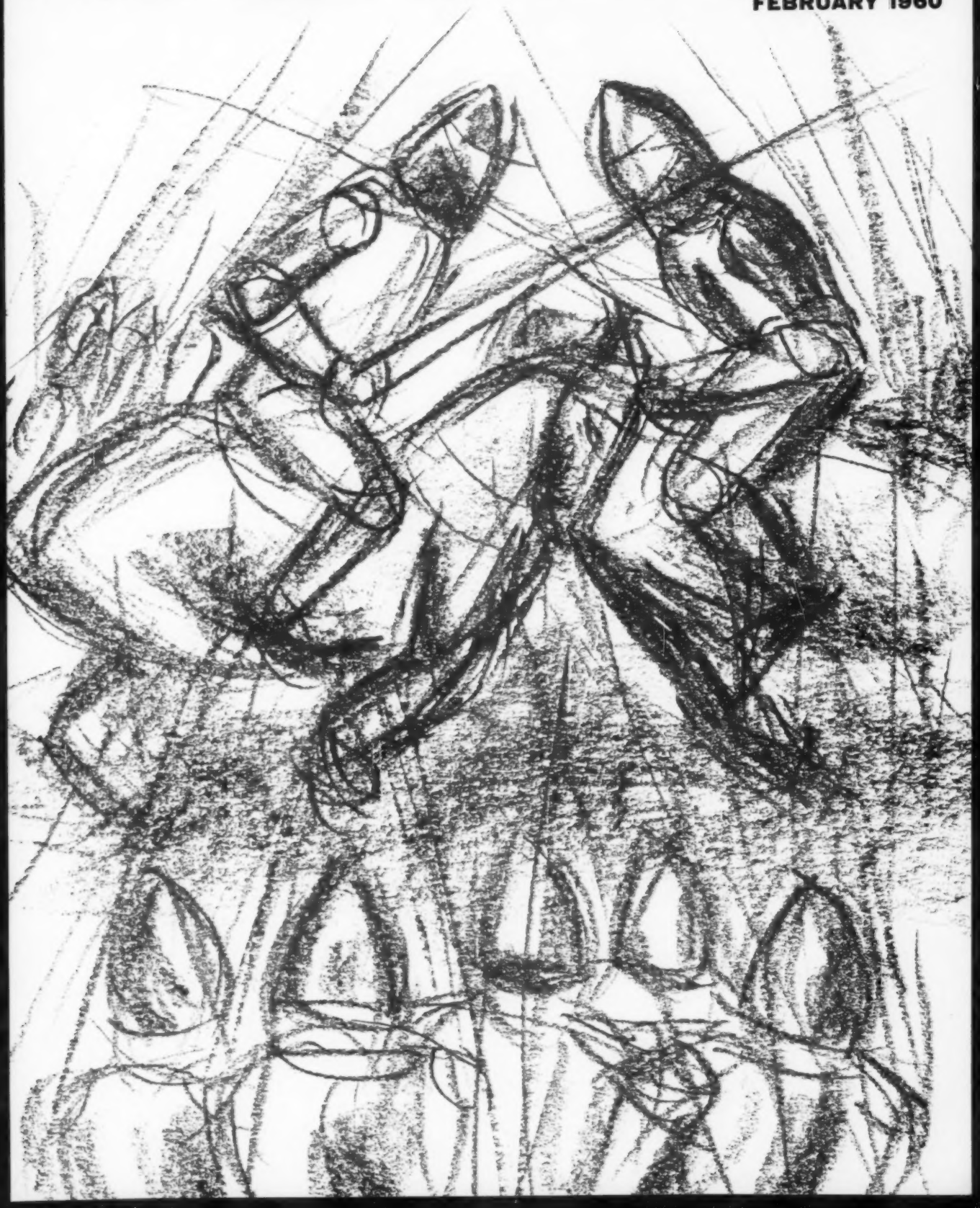
JOURNAL OF

METALS

FEBRUARY 1960



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JOURNAL OF

METALS

Vol. 12, No. 2
February, 1960

COVER: On with the tournament . . . the conflict between steel and titanium. Featured in this issue is the symposium, Titanium vs Steel, presented at the Fall Meeting of The Metallurgical Society. Cover is by David Cain.

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personnel

• These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the societies of Civil, Electrical, Chemical Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 5% of the first year's salary if a non-member, or 4% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately, by our office, after receiving your application. In sending applications be sure to list the key and job number.

• When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

—MEN AVAILABLE—

All those listed under "Men Available" have membership in the AIME.

Metallurgist; B.S. Met. Two years in integrated steel mill; 4 years research in titanium and reactive metals; 3 years process metallurgy Desires position in process metallurgy. Prefer Midwest, West, or Southwest. M-1032-Chicago.

Designer, Supervisor; age 40. Nineteen years experience in plant design, negotiation of contracts, consulting, maintenance, and engineering for mining and refining plants and electrical manufacturer. $14,500. Locate anywhere in US Se-1614.

Supervisor; graduate in mining and metallurgy, age 55. Thirty years experience in examination, exploration, development, and operation in nonferrous metal mines, mills, and allied fields. Licensed professional engineer. $7800. Prefer West. Se-1580.

Sales Engineer; graduate metallurgist, age 50. Twenty-five years mining and milling experience, including plant construction and design; business manager in purchase of ores and disposal of concentrate for custom mill. $9600. Any location. Se-1545.

Designer, Superintendent; graduate mechanical engineer, age 37. Five years as mechanic and machinist; 10 years as design engineer and construction superintendent; 4 years as operating metallurgist. Qualified in labor relations. $9600. Prefer San Francisco bay area. Se-1419.

General or Project Manager; graduate mining and metallurgical engineer, age 47. Twenty-five years experience in mining, milling, and project engineering in US, South America, Europe, and Australia. Thorough knowledge of management problems; has operated own company. $12,000. Any location. Se-1866.

Professor or Geologist; B.S. Min Eng, Ph.D. geology, age 44. One year's experience teaching and geological research for university. Twelve years experience as chief engineer and geologist on studies, mapping, reports, and exploration. Has also been metallurgical consultant on tungsten. $12,000. Prefer New York, San Francisco, or foreign. Se-1297.

Junior Metallurgist; M.S. Met Eng, age 28. Recent graduate, but has actual experience in drafting, ore dressing, and assaying, with background of X-ray diffraction and ceramics. Salary open. Any location. Se-549.

Mill Superintendent, age 63. Thirty years experience in ore dressing research and operation of nonferrous ore beneficiation plants. Proven ability to cut costs and increase recoveries. Locate anywhere. Salary open. Se-461.

Plant Manager or Process Engineer; Chem E, age 47. Professional license, N. Y. state. Twenty years experience as process engineer, plant manager, and chief metallurgist for following processes: sponge iron and acid manufacturing, rhenium extraction, nonferrous metal production, aluminum smelting, tin volatilization, test coking coals, and reduction and purification of uranium metal. $12,000. Any location. Se-1108.

Metallurgical Engineer; graduate, age 32. Eight years as metallurgist for zinc and lead smelters; 2 years in analysis and testing at flotation mill. $8400. Prefer West. Se-488.

Metallurgist, graduate, age 24. One year as process engineer developing and improving new and existing metallurgical practices for electric furnace manufacture of ferro and special intermediate alloys. Small-scale pilot work for refractories. One year production engineering trainee in development for ferro alloy and calcium carbide manufacturer. $7000. Prefer San Francisco bay area or West. Se-1214.

Metallurgist; graduate, age 40. Eleven years supervising personnel and metallurgy in lead smelters . . . research on casting techniques at cadmium refinery . . . foreman at copper refinery . . . and foreman of aluminum rolling mill. $8400. Prefer Calif. or Northwest. Se-927.

Superintendent or Sales; graduate mining and metallurgy, age 45. Extensive experience in field work, lab, design, and operation of flotation, gravity, and chemical plants. Also sales engineering and management. $9600 up. Prefer West or foreign. Se-802.

—POSITIONS OPEN—

Address replies for positions to the nearest local office of the Engineering Societies Personnel Service, Inc., *not* to the JOURNAL OF METALS. Offices are located at 29 E. Madison St., Chicago 1, Ill. . . . 57 Post St., San Francisco, Calif. . . . and 8 W. 40th St., New York 18, N. Y.

Extractive Metallurgist for responsible position in research and development program in electric furnace smelting with young, progressive company. Some furnace experience desirable. Salary dependent on qualifications. Location: East. W8331.

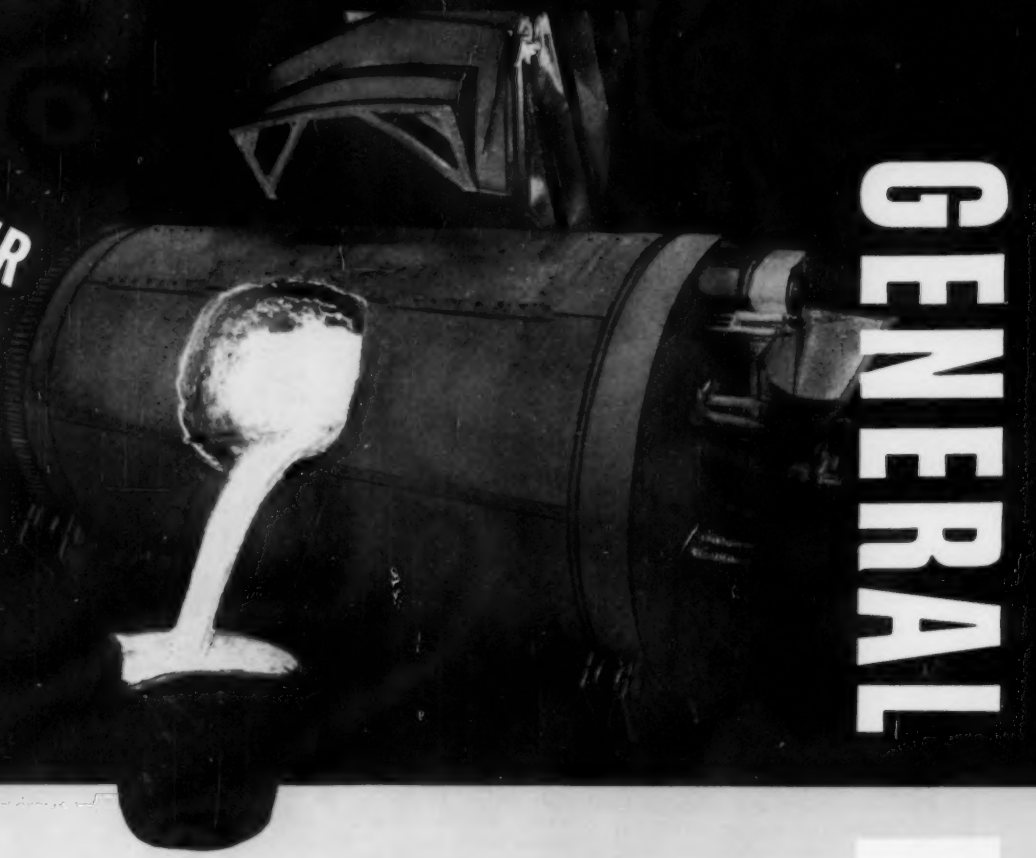
Metallurgist with at least five years open-hearth steel and flat rolling mill experience. $9600 to $12,000. Location: East. W8311.

Metallurgists. a) Metallurgist with M.S. and two to four years experience in physical metallurgy research, including research and development experience with both aluminum and high-strength steel alloys. Experience in the aircraft missile field desirable. Salary to $8000. Location: northern N. J. b) Metallurgist with physical metallurgy research on heat-resistant alloys; M.S. in metallurgical engineering preferred, but not required. M.E. degree acceptable with some metallurgical background. Prefer two to four years experience in physical metallurgy research, including one year of test laboratory experience and two to three years broader research experience in heat-resistant alloy field. Salary to $8000. Location: northern N. J. c) Project engineer for a nonferrous foundry producing bronze and copper castings and bearings. Degree in metallurgical engineering plus one to three years practical experience preferred. Foundry experience and strong interest in foundry operating problems desirable. Salary to $7800. Location: Pa. Company pays placement fees. W8307.

Metallurgists. a) Supervisor for nuclear fuel research. Ph.D. or equivalent experience in metallurgy or metallurgical engineering preferred. Chemical engineering degree

(Continued on page 100)

CONVERTER NEEDS ARE BASIC!



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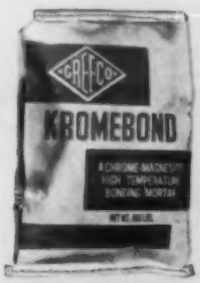

KROMEBOND air-setting chrome magnesite mortar

GREFCO M burned magnesite brick

PERSONNEL

(Continued from page 98)

with heavy metallurgical experience acceptable. Must be experienced in nuclear or physical metallurgy in order to plan and carry out metallurgical programs involving alloy development, nuclear fuel, and atomic reactor components. b) Metallurgists for nuclear fuel research. B.S., M.S., or PhD. with up to five years experience and top notch research potential. For new nuclear fuel research laboratories. Location: New York. W8302.

Physical Metallurgist with degree in metallurgy and four years experience, including two years of specialized experience. Will serve as technical expert and advisor in field of metallurgy as it relates to research and development activities, installation, operation, and maintenance of nuclear reactor power plants. $10,130. Placement fee paid. Location: Md. W8292.

R&D Engineers or Physicists with B.S. or better. To conduct experimental investigations of radically new processes and products in the field of packaging, utilizing metal, paper, plastic, glass, and other materials. Under supervision of research director. Must be US citizen and draft exempt. Salary dependent on experience. Employer will pay placement fee. Location: Chicago. C7838.

Manager for research and development. Graduate metallurgical engineer with at least five years experience in supervisory work in brass, bronze, cast iron, and possibly steel foundry. Should have processing experience in foundry. Requires knowledge of machining problems relative to specific metals . . . familiarity with administrative and technical aspects of research and development . . . metallurgy and process control . . . sales engineering . . . and quality control. Will be responsible for staff of nine engineers. Should be willing to live in small town. $12,000 plus bonus. Location: Ohio. C7841.

Process and Sales Engineer; understudy for plant or management in non-metallic minerals company. Mining or buying non-metals for processing and selling in central Calif. Start in mining, training to do labor jobs, advance to production, and finally into commercial aspects. Might be a permit man in mine or mill union. Prefer to fill the need with professionally-trained man. About $5400 to start. Location: San Francisco. Sj-4904-R.

Research Engineers; a) Fabrication research engineers with B.S. M.S., or Ph.D. in metallurgical or mechanical engineering. Minimum six years experience in metal processing (press working, spinning, machining, chemical milling), high-strength steels, titanium, and refractories. Some experience in research and development of metal fabricating processes and techniques desirable. b) Welding research engineers with B.S., M.S. or Ph.D. in metallurgical or mechanical engineering. Minimum of six years experience welding and/or brazing high-strength steels and refractories. Some research and development of metal joining process and techniques desirable. c) Metallurgical engineers with B.S., M.S., or Ph.D. in metallurgy or mechanical engineering, with experience in metal process or metal joining of high-strength steels. $9000 to $15,000. Location: northern Calif. Sj-4903-R.

Buyer—Water Service; graduate in bus adm, metallurgy, or Chem E. Prefer two years experience in purchasing, engineering, heavy construction, stock control, or storekeeping which has provided a detailed knowledge of heavy construction materials, equipment, and office supplies . . . standard price and purchase reference sources . . . budgeting . . . bookkeeping . . . contracts and inventory control . . . and the legal aspects of purchasing. Ability to read and interpret civil and mechanical engineering drawings necessary in order to maintain records and make calculations. Should be US citizen. $6200 to $7100. Location: San Francisco bay area. Sj-4882.

Research Engineer; M.S. in Met E, Chem E, or Chem, or B.S. with exceptionally strong research experience. Must be interested in applying knowledge to solution of industrial problems rather than to fundamental research. Department conducts applied research and development on new processes and major process improvements in fields of mineral beneficiation, hydrometallurgy, and pyrometallurgy. Salary commensurate with training and experience; liberal fringe benefits. Location: West. Sj-4876-R.

Consultant Metallurgist; graduate with wide metallurgical experience in copper smelting and refining. Should be familiar with operations and engineering in copper-producing areas throughout the world. Will provide technical direction for metallurgical plant and design construction, also technical assistance to operation smelters. Must be top-notch, with sound economic sense, and be capable of contact work under variety of circumstances, including top management. Salary commensurate with experience. Headquarters: Mountain States. Sj-4866-R.

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NEW BULLETIN

A new bi-weekly bulletin of "Engineers Available" is now being published by the Engineering Societies Personnel Service, Inc. Distributed free of charge, the bulletin contains synopses of the experience of engineers who have registered with the Service and are seeking a new position.

Any employer interested in receiving the bulletin should so advise E.S.P.S. at 8 W. 40th St., New York 18, N.Y., and your name will be placed on the mailing list. Any engineer who is registered with the Service or wishes to register is entitled to a 35-word notice in the bulletin. Write to the New York office for forms. Your qualifications will be brought to the attention of employers on our mailing list without revealing your identity.

It is planned to extend the publication to the midwestern and western offices in the near future.

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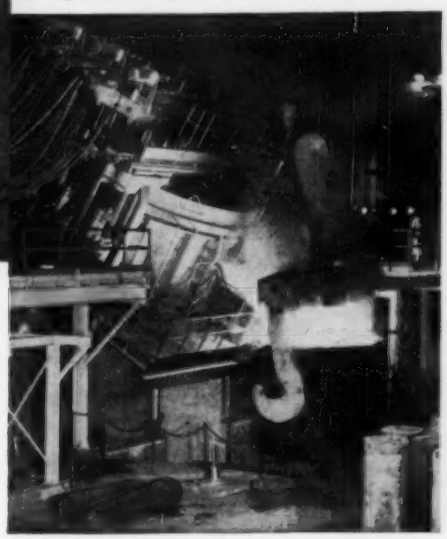

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By Bruce Chalmers, *Harvard University*. Applies scientific rather than empirical approaches, building a physical framework and examining its validity by comparison with experiments. *1959. 468 pages. $12.50*

2. THE NATURE AND PROPERTIES OF ENGINEERING MATERIALS

By Z. D. Jastrzebski, *Lafayette College*. Much more basic than the usual treatment, it stresses materials from the engineering point of view, with realistic applications. *1959. 576 pages. $11.00*

3. FOUNDRY ENGINEERING

By Howard F. Taylor, Merton G. Flemings, and John Wulff, *all of M.I.T.* Thoroughly modern, covering principles and methods of today's materials and processes in foundry operation. *1959. 408 pages. $8.75*

4. FRACTURE: AN INTERNATIONAL SEMINAR ON THE ATOMIC MECHANISMS OF FRACTURE

Edited by B. L. Averbach, *M.I.T.*, D. K. Felbeck, *Nat'l Academy of Sciences*, and D. A. Thomas, *M.I.T.* Theory and experiments of cleavage, ductile fatigue, high-temperature mechanisms of failure. A Technology Press Book, M.I.T. *1959. 646 pages. $17.50*

5. STRUCTURE AND PROPERTIES OF THIN FILM

Edited by C. A. Neugebauer, J. B. Newkirk, and D. A. Vermilyea, *all of General Electric Research Laboratory*. The record of a recent international conference, including current research and transcript of the discussions. *1959. 561 pages. $15.00*

6. RANDOM VIBRATION

Edited by S. H. Crandall, *M.I.T.* Basic concepts and tools needed to deal with random vibration—a new problem introduced by rocket and jet engines. A Technology Press Book, M.I.T. *1959. 423 pages. $8.50*

7. MECHANICAL PROPERTIES OF INTERMETALLIC COMPOUNDS

Edited by J. H. Westbrook, *General Electric Research Laboratory*. Based on a recent symposium sponsored by the Electrothermics and Metallurgy Division, Electrochemical Society, Inc. 1960. *452* pages. *$9.50.*

8. KINETICS OF HIGH-TEMPERATURE PROCESSES

Edited by W. D. Kingery, *M.I.T.* High-temperature processes in general, nonmetal systems in particular. Covers both basic research and applications to actual systems. A Technology Press Book, M.I.T. *1959. 326 pages. $12.50*

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By W. D. Kingery, *M.I.T.* The first to cover thoroughly materials and measurements of properties above 1400°C (2500°F). *1959. 416 pages. $16.50*

10. EXTRACTIVE METALLURGY

By Joseph Newton, *University of Idaho*. Gives total coverage of the field, stressing the basic principles involved. *1959. 532 pages. $9.75*

ALSO . . . 11. ABSTRACTS OF THE LITERATURE ON SEMICONDUCTING AND LUMINESCENT MATERIALS AND THEIR APPLICATIONS, Compiled by Battelle Memorial Institute. 1957 edition. In Press . . . 12. SCIENTIFIC RUSSIAN, By G. E. Condoyannis. 1959. $3.50

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personals

David C. Minton, Jr., has been appointed to the Materials Advisory Board of the National Academy of Science's div. of Engineering and Industrial Research. Mr. Minton also holds the position of vice president at Battelle Institute, where he plans and organizes its research activities.

Hal W. Maynor, Jr., is now prof. of Mechanical Engineering at Alabama Polytechnic Institute. He resigned his position as assoc. prof. of Metallurgical Engineering, the University of Kentucky, to accept the new post. At Alabama Tech he will also be a member of a research team studying fracture phenomena in certain high-strength metallic materials. The study is under the sponsorship of the Army Rocket and Guided Missile Agency, Redstone Arsenal, Ala.

D. D. Barbor has been named manager of sales for manganese products, Union Carbide Metals, Co., div. of Union Carbide Corp. Before his new appointment, he was an assistant in technical control, and still earlier was in metallurgical production with steel and ferroalloy producers.

Paul von Stein has joined the sales staff of Seaboard Refractories Co., Fords, N. J. He is Technical Sales Manager for the Company. He was formerly engaged in research and developmental work with the American Metal Co. and American Smelting & Refining Co.

Francis J. Shortsleeve, asst. dir. of research at Union Carbide Corp.'s Niagara Falls laboratories, is heading a research program on the nature of metallic solid solutions in co-operation with the US Atomic Energy Commission. Working with Dr. Shortsleeve are Dr. **W. W. Webb,** Dr. T. J. Rowland, and Dr. H. T. Pinnick. Under particular study will be electron transport, X-ray diffraction, and nuclear magnetic resonance.

J. W. Burgess is now chief engineer for American Zinc, Lead & Smelting Co. He has been with American Zinc since 1941, and was most recently manager of construction at the Uranium Reduction Co., a subsidiary.

Howard B. Myers has been elected a vice president of Tennessee Products & Chemical Corp. He will continue to head metallurgical sales for the firm, in addition.

Raymond L. Smith is now chairman of the Department of Metallurgical

(Continued on page 108)

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NOHC, Blast Furnace Coke Oven, Materials Conference Apr. 4-6

Plans for the AIME's 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference are slowly rounding into shape. The joint Conference is destined for the Palmer House, Chicago, Apr. 4-6.

The Blast Furnace, Coke Oven, and Raw Materials portion of the program is now in tentative form. Meeting simultaneously at 9 am to 12 m on Monday, Apr. 4th, are sessions on blast furnace practice, iron ore reduction, and coal. That afternoon, 2 pm to 5 pm, will come sessions on blast furnace theory and coke.

The morning of Tuesday, Apr. 15th, will be devoted to simultaneous sessions on sintering, coal chemicals, and computer simulation. A joint session encompassing processes from each of the three areas will take up the afternoon.

Wednesday, Apr. 6th, will be devoted to plant trips to the Acme Steel Co., Riverdale Station, Chicago, Ill.; and the sintering plant of Inland Steel Co., East Chicago, Ind.

education

Copper-Brass Award

► A prize of $1000 and a bronze award is being offered for the "most outstanding contribution to the use, application, or metallurgy of copper and copper-base alloys." Sponsor of the award is the Copper & Brass Research Association. Last year's Copper and Brass Achievement Award was given in recognition of the Seagram Building in New York, the world's first all-bronze skyscraper.

Entries may be submitted in one of several classifications, with primary consideration to be given contributions to the metallurgy of copper metals . . . design of new or established applications of copper, brass, bronze, or other copper-base alloys . . . and contributions to science or research through the application of copper metals.

Nominations must be received by Mar. 31st. Entry forms and complete information is available from the Copper & Brass Research Association, 420 Lexington Ave., New York 17, N. Y.

X-ray Research

► A total of $224,600 has been granted Cornell University for research in X-ray spectroscopy. Sponsors of the research are the Air Force, with $190,100; and the National Science Foundation, $34,500.

Under study are the inadequacies of conventional X-ray energy level diagrams for use in gaseous, liquid, and solid materials. Researchers seek a better understanding of the diagrams, based on the so-called many-electron view of the dynamics of atomic behavior. The second phase of research concerns the physical and chemical structure of solid surfaces. The Cornell group has developed a new method of study, based on the reflection of X-rays from surfaces.

Backofen Awarded $2000 Teaching Prize

Walter A. Backofen, assistant professor of metallurgy, Massachusetts Institute of Technology, has received the American Society for Metals Teaching Award for 1959.

The $2000 cash award is granted annually to an outstanding young educator in the metals field.

RESEARCH METALLURGIST

(Ph.D. or M.S.)

is needed to act as Project Leader on challenging programs concerning refractory metals and other reactor materials. Applicants should possess several years of related research and development experience although personal drive, enthusiasm and ambition are more important than specific technical experience. Our environment is midway between academic and industrial research and, insofar as practical, offers the opportunity to develop research programs of greatest appeal to your personal interests. Professional development is encouraged through publication of papers and participation in professional activities. Imaginative thinking is highly valued and the individual abilities of our dynamic staff are recognized and rewarded.

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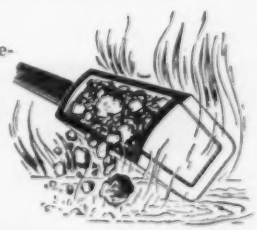

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IMD BYLAW REVISION

All members are hereby notified that the following amendment to the Bylaws of the Institute of Metals Division of The Metallurgical Society of AIME was proposed at the meeting of the Executive Committee on Nov. 3, 1959, and will be voted on at the annual Business Meeting of the Division, to be held at 11:45 a.m. on Tuesday, Feb. 16th, in the Ballroom of the Sheraton-Atlantic Hotel in New York City:

Article VIII, Section 13—Publications Committee. The duties of the Publications Committee shall be to examine and review all papers in its field submitted to the Society for publication in TRANSACTIONS OF THE METALLURGICAL SOCIETY OF *AIME;* to evaluate reader comment obtained on each paper; and to recommend to the Publications Committee of The Metallurgical Society as to acceptance or rejection of papers for TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME. It also may assist the Editor of JOURNAL OF METALS on the acceptance of papers in its field for publication.

This amendment is required because this section as presently worded is inconsistent with the Bylaws of The Metallurgical Society of AIME; such inconsistency violates Article I, Section 1 of the IMD Bylaws.

D. C. Johnston
Secretary

letters to the editor

References Omitted

In the November edition of JOURNAL OF METALS the paper by H. B. Wendeborn, M. O. Peucker, and W. P. Massion on *Updraft Sintering of Lead Concentrates* which has been reported in San Francisco, has been published. In this publication the essential improvements which we had entered in the proof sheet were considered. The references were, however, not mentioned. We would request you most urgently to consider the references in the next possible edition of the JOURNAL OF METALS, since with the present form of the publication a wrong impression may be created. We wish to give you, hereunder, once more the references:

[1]H. Wendeborn, *Erzmetall* VII (1954) pp. 3-11.

[2]W. R. Burrow, K. L. Ridley and F. C. Adams, *Proc. Aust. Inst. Min. Met.* No. 180 (1956) pp. 179-206.

[3]R. Schmidt, R. Fischer, and G. Ebeling, *Erzmetall* XI (1958) pp. 301-310.

[4]S. J. Wallden, N. B. Lindvall and K. G. Gorling, *Trans. Met. Soc. AIME,* Vol. 212 No. 2 (1958) pp. 146-153.

Lurgi Gesellschaft
für Chemie und
Hüttenwesen M. B. H.

[The references were omitted from the article because of space requirements. Sorry. Ed.]

New Powder Metallurgy Society Seeks Members Among Fabricators

Formation of a technology division has been announced by the Metal Powder Industries Federation (MPIF). Called the American Powder Metallurgy Institute (APMI), division membership is open to anyone with a bonafide interest in powder metallurgy.

The new organization is not attempting to compete with the AIME's jurisdiction in the field, as provided by the Institute of Metals Division's Powder Metallurgy Committee, according to Kempton Roll, Executive Secretary of MPIF. Rather, it is designed to complement AIME's activities. The Powder Metallurgy Institute's activities are geared to the fabrication and processing of powder metal parts, whereas the Powder Metallurgy Committee of AIME is fundamentally concerned with the metallic quality of such parts.

Annual dues for APMI membership is $10; $15 to foreign members. An initiation fee of $5 is also required. But for those who join the Institute before Apr. 25th a charter member status will be conferred; in addition the $5 initiation fee will be waived.

Receipt of newsletters and discounts on society publications are among the advantages in membership in addition to section meetings. For more information, contact: *Kempton H. Roll, Executive Secretary, Metal Powder Industries Fdt., 60 E. 42nd St., New York 17, N. Y.*

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EDITORIAL

The Teacher as Human Being

Dept. Chairman: "What can I do for you, Watson?"

Assistant Professor: "Well sir, I wouldn't talk about a raise in salary, normally, but at this time of year the ground is frozen, you know, and the children can't dig for roots or hunt berries. . . . ."

• • •

After keeping tab on who has been saying what in the education field for about three years, I have come to the conclusion that the above dialogue expresses the "education problem" much more eloquently than piles of press releases from the various organizations which consider this troublesome matter.

While there is no doubt that a great deal of attention has been given to the problem of teacher's salaries, curricula, and student selection, the ultimate result of all this effort is nothing more formidable than a person standing in front of a room full of live students. What goes on there is what determines what a graduate knows, and even more important, how he thinks.

Since colleges hire teachers for scholarship rather than teaching ability, and advancement comes the same way, what goes on in the classroom can only too rarely be called *teaching*. Who does not remember the professor of calculus who just couldn't understand your lack of comprehension of such *plainly obvious* concepts? Or the physics man who was so wrapped up in research projects that to approach him outside the classroom was next to impossible or, if done, considered an affront to his *teaching* ability? Conversely, every reader can look back on his college days and remember one or two teachers who were truly outstanding in their effect. These men, by their own enthusiasm, consistently infected their students with a curiosity and an urge to learn that did not end with the final examination.

And what rewards do these *real* teachers receive for this priceless service? The lasting gratitude of their students is one thing, and a lucky thing it is that they appreciate this, for there is precious little else. The more they are concerned with teaching, the less they can devote to publishing, with the result that they are largely ignored by their profession, which hurts the pride, and they get similar treatment at the hands of university and department officials, which hurts the pocket.

Unlike some other professional problems, there is a great deal that The Metallurgical Society could do in this area. Annually, we honor those who have written *best papers* in a variety of fields, and the conclusion that our highest awards go to those who have published most does not seem to be too farfetched. Is it inconceivable that the Society or its divisions could honor a *teacher* of metallurgy in a similar fashion? With attendant publicity, this might have the double-barrelled effect of impressing both underpaid teachers of metallurgy and university officials with the fact that, at least in this profession, *teaching ability* is something that is professionally recognized and praised.

Selection procedures would have to be worked out by an award committee. A simple procedure would be to ask graduates who felt strongly about a teacher to write in about him. The alumni groups that meet annually at the Fall Meeting might provide another avenue of approach.

Curricula changes and secondary preparation have important and well-evaluated effects. But without teachers who are men of vision—who feel that teaching the young is even more important than deformation characteristics of copper-base solid solution alloys—without these men we will not get the caliber of graduate we so urgently need. Since, as individuals, we are without the ability to wave the philanthropic wand over the salaries of these men, can we not at least recognize their achievement and lasting contribution?

J. J. Burke

PERSONALS

(Continued from page 102)

Engineering, Michigan College of Mines and Technology. Dr. Smith was formerly technical director of the Franklin Institute Laboratories.

Thomas J. Ready, Jr., has been named to the newly-created position of executive vice president of Kaiser Aluminum & Chemical Corp. His former position was that of vice president and assistant general manager in charge of aluminum operations.

B. D. Thomas, president of Battelle Memorial Institute, was a principal speaker at the American Society of Industrial Designers' annual meeting in November. Dr. Thomas told the designers of a number of technological advances, particularly in metallurgy and plastics, that will effect product design in years ahead.

Walter L. Havekotte is now chief project engineer with A.M. Byers Co., Ambridge, Pa. He was formerly with Firth Sterling, Inc.

Richard C. Trushel has been transferred to St. Louis as the sales representative for Ohio Ferro-Alloys Corp. in that territory. His former base was Canton, Ohio.

G. M. Butler, Jr., has resigned as director of The Carborundum Co.'s Research and development division. Taking his place will be **Donald G. Sturges,** formerly associate director of the division.

Edward J. Dulis is manager of product reseach of Crucible Steel Co.'s Central Research Laboratory—a newly-created position. He was formerly supervisor of high-temperature materials and welding research.

M. D. Ayers has been appointed director of engineering at Kennecott Copper Corp. With Kennecott since 1956, Mr. Ayers has previously been engaged in special assignments as assistant to the president.

Eugene A. March is now assistant works manager of Crucible Steel Co.'s Midland, Pa., plant. He was formerly division superintendent of technical services.

L. A. Harrison and **Philip A. Gaebe** were among promotions recently announced by Kaiser Refractories & Chemicals, subsidiary of Kaiser Aluminum & Chemical Corp. Both will make their headquarters in Pittsburgh. Mr. Harrison has been appointed general sales manager of the Eastern div. of Kaiser Refractories & Chemicals. Mr. Gaebe will assist him in those duties.

E. B. Speer has been appointed administrative vice president of central operations (Steel and Coal), for the U.S. Steel Corp. Earlier last year, Mr. Speer was made vice president of operations at U. S. Steel.

James A. Hudson has assumed the post of Western sales manager of bulk gas sales for the Linde Co., div. of Union Carbide Corp. He was formerly Midwestern manager of gas products sales for Linde.

A. L. Hodge is now associate manager, development of gas processes (metallurgy), Newark Development laboratory, Linde Co. Mr. Hodge has been with Linde since 1947. At Linde, and previously with the Gary works of U. S. Steel Corp., Mr. Hodge has been engaged as a research metallurgist in the development of iron and steelmaking processes.

Cyril S. Smith has resigned his position on President Eisenhower's Science Advisory Committee in order to devote full time to his post as professor of metallurgy at the Institute for the Study of Metals, University of Chicago.

Herbert W. Graham will head a newly-formed research consulting organization called TEAM, Inc. Mr. Graham, formerly vice president of research, Jones & Laughlin Steel Corp., explains that "Members of the organization are retired executives of some of the largest industrial companies in the U.S."

Paul D. V. Manning is among the founder members of the organization. Dr. Manning was formerly vice president of research, International Minerals & Chemical Corp.

Christian N. J. Wagner has joined the Dept. of Metallurgy at Yale University. Dr. Wagner, a native of Germany, was most recently a visiting fellow in the X-ray Diffraction Laboratory, Massachusetts Institute of Technology. Before that, he was a research and teaching assistant at the Institut fuer Metallphysik and Metallkunde, University of the Saar.

Arthur E. Powers has joined the staff of Knolls Atomic Power Laboratory as a physical metallurgist in the materials development division.

Dr. Powers was in the Schenectady, N. Y., power tube dept. of General Electric Corp. before joining the GE-operated Laboratory of Knolls.

John L. Tatman has joined J. R. Miller Co., New York consulting firm, as a metallurgical engineer. He brings with him a background of 35 years of blast furnace and rolling mill assignments.

(Continued on page 116)

J&L STEEL

RESEARCH METALLURGISTS

Continuing growth of the J&L research and development program has created a number of openings for professional personnel, holding Ph.D., M.S., or B.S. degrees in metallurgy or a related scientific field. Projects underway or in prospect cover a diversity of subjects in physical and process metallurgy, all of course, related to the production of carbon and stainless steels, and all company supported. Because of this diversity, it is almost always possible to accommodate individual interests. The J&L Research Division is housed in the modern, air-conditioned, fully-equipped Graham Laboratory in suburban Pittsburgh. Attractive residential areas are close by. And progressive Pittsburgh offers many advantages, including full graduate programs at the University of Pittsburgh and Carnegie Institute of Technology for the man who wants to continue his professional education.

If you have these interests, we would like to hear from you, and will respect your confidence. Write.

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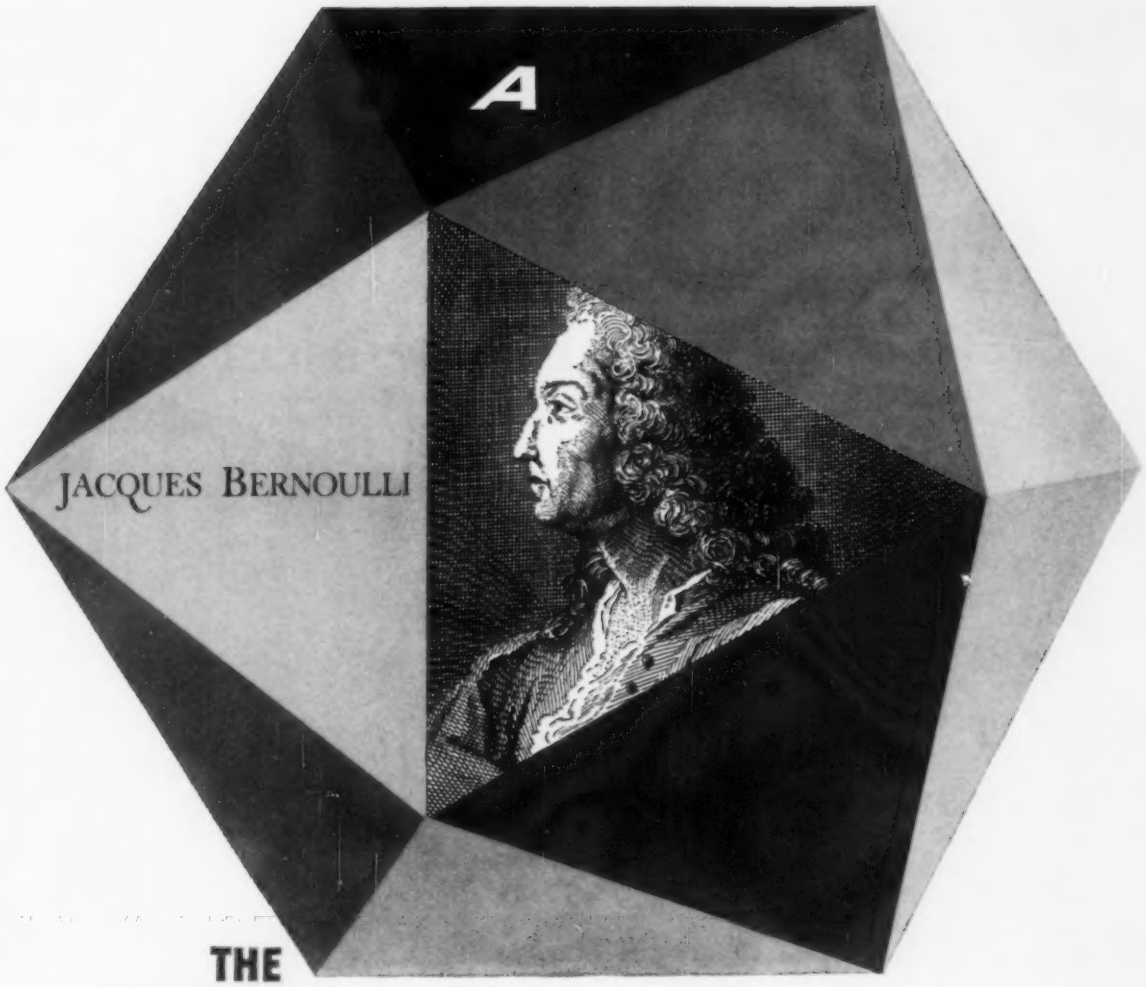

THE WIZARD OF ODDS

He solved a telephone traffic problem two centuries ago

Jacques Bernoulli, the great Swiss mathematician, pondered a question early in the 18th century. Can you mathematically predict what will happen when events of chance take place, as in throwing dice?

His answer was the classical Bernoulli binomial distribution—a basic formula in the mathematics of probability (published in 1713). The laws of probability say, for instance, that if you roll 150 icosahedrons (the 20-faced solid shown above), 15 or more of them will come to rest with side "A" on top only about once in a hundred times.

Identical laws of probability govern the calls coming into your local Bell Telephone exchange. Suppose you are one of a group of 150 telephone subscribers, each of whom makes a three-minute call during the busiest hour of the day. Since three minutes is one-twentieth of an hour, the probability that you or any other subscriber will be busy is 1 in 20, the same as the probability that side "A" of an icosahedron will be on top. The odds against 15 or more of you talking at once are again about 100 to 1. Thus it would be extravagant to supply your group with 150 trunk circuits when 15 are sufficient for good service.

Telephone engineers discovered at the turn of the century that telephone users obey Bernoulli's formula. At Bell Telephone Laboratories, mathematicians have developed the mathematics of probability into a tool of tremendous economic value. All over the Bell System, the mathematical approach helps provide the world's finest telephone service using the least possible equipment. The achievements of these mathematicians again illustrate how Bell Laboratories works to improve your telephone service.

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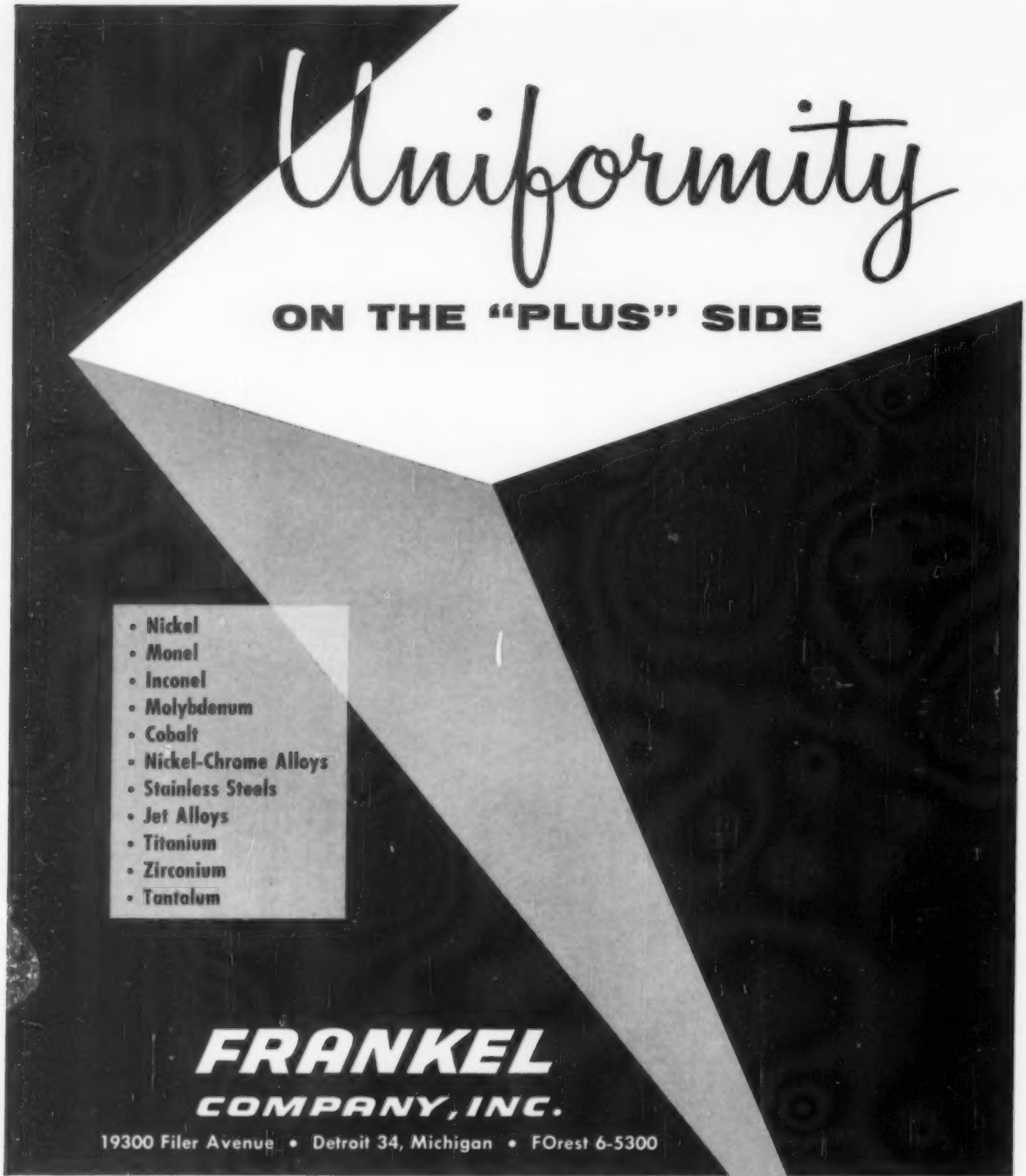

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USBM reports 1959 outputs

Aluminum: US Bureau of Mines figures show that aluminum production reached and all-time high of 1.95 million tons in 1959. This was 16 pct higher than the previous peak recorded in 1956.

Start-up of new facilities during the year helped account for the record output. Early in 1959, Oregon Metallurgical Corp. began operating its fifth and last line in Ohio. As the year progressed, two new lines were activated by Kaiser Aluminum & Chemical Corp. in West Virginia with completion of its plant there. Reynolds Metals Co. tapped metal from the first of three lines at its new St. Lawrence, N. Y., plant in 1959. Thus, by year's end, domestic capacity for primary aluminum had increased by 140,000 tons to a total of 2.4 million tons annually.

The Aluminum Co. of America and Reynolds Metals Co. are continuing construction of new facilities which, upon completion, will bring domestic capacity to 2.6 million tons.

Magnesium: Production of primary magnesium was 31,000 tons in 1959—an increase of 1000 tons over 1958. Shipments of 46,000 tons spelled a 35 pct increase over the previous year. The year 1959 also saw completion of Alabama Metallurgical Corp.'s 7000-ton silicothermic plant at Selma, Ala. Production of magnesium from dolomite began in November.

Zirconium: Reactor-grade sponge production during 1959 was up 8 pct over 1958. Mallory-Sharon Metals Corp. produced sponge at its Ashtabula, Ohio, plant, while the Parkersburg, W. Va., plant of Carborundum Metals Co. was in full production during the year. Smaller amounts of sponge were produced by the Wah Chang Corp., where at year's end they were installing new melting and fabricating facilities. Columbia-National Corp. also accounted for some of the supply before shutting down at the end of the year for alteration and repair.

Facilities for melting sponge to ingot remained ahead of sponge capacity, with Westinghouse Electric, Allegheny Ludlum Steel, Harvey Aluminum, Mallory-Sharon Metals, and Oregon Metallurgical doing the melting.

Hafnium: Hafnium sponge and crystal bar were produced from materials separated in the zirconium purification process. Most of the product was under contract to the Atomic Energy Commission. The AEC also placed a separate contract with Carborundum Metals Co. for production of hafnium sponge from Nigerian high-hafnium zircon concentrate.

Columbium-Tantalum: Columbium production in the US more than doubled for the second successive year, and output of tantalum metal increased more than one-third. Prices for columbium ingot dropped to about $35 a lb; $45 a lb for tantalum ingot. Earlier in the year both metals had brought $65 a lb.

Higher purity tungsten

A vapor deposition process for making useful shapes of high-purity tungsten has been developed by the Rolla, Mo., laboratory of the US Bureau of Mines. V. A. Nieberlein and H. Kenworthy of the laboratory formed 99.996 pct purity tungsten into tubing. The effort is reported in bulletin No. 5539, available from the Distribution Section, Bureau of Mines, 4800 Forbes Ave., Pittsburgh 13, Pa.

New Cb-base alloy formed

A medium-strength columbium-base alloy containing 7.5 pct Ti and 0.75 pct Zr is reported to have an ultimate tensile strength of 37,000 psi at 1800°F. The alloy, called Cb-65, was developed at the Product Development Laboratory of Union Carbide Metals Co., div. of Union Carbide Corp.

The new alloy is designed to maintain low neutron cross section and to provide increased mechanical strength and oxidation resistance over that of pure columbium, while retaining a high degree of workability and notch toughness.

Cb-65 is the first of a family of new columbium-base refractory alloys, all with higher strengths and temperature limits, which are now under development at the Company's laboratories. Ultimate tensile strengths in excess of 40,000 psi at 2200°F appear to be obtainable on the basis of data resulting from research efforts.

40-in. electrode furnace

A contract for the design and construction of reportedly the world's largest vacuum melting furnace has been placed by Midvale-Heppenstall Co. The furnace will be designed to melt electrodes of alloys and steels of varying compositions. Resulting ingots will be 40 in. in diam and weigh some 25 tons.

Consolidated Vacuum Corp. of Rochester, N. Y., subsidiary of Consolidated Electrodynamics Corp., and Heraeus GmbH of Hanau, Germany, are uniting to fulfill the contract. The furnace design will follow Heraeus' previously-built smaller models, (See JOURNAL OF METALS, March, 1958, pp. 193 to 198.). Heraeus will supply some of the vacuum and electronic control equipment, but the majority of the components will be produced in the US.

Projected annual capacity for the furnace is 8000 tons, a portion of which will be sold as semi-finished slabs and billets. However, most of the output is expected to be used in the plants of Heppenstall Co. The vacuum-melted ingots will be converted into heavy forgings by the open-die process on flat die presses and hammers. Rough and finished machined forgings will be manufactured for the Company's regular customers who produce equipment in which highly-stressed parts require maximum metal cleanliness.

REPORTER

Steelmaking figures reported

The revolution in steelmaking as precipitated by the basic oxygen processes, (pointed out in the table found on p. 21 in the January issue) continues to be emphasized in more recently issued figures.

The American Iron and Steel Institute January 1, 1960, figures show continued growth in oxygen converter and electric furnace capacities, while the bessemer process is in continuing decline, and open-hearth growth has nearly stopped.

LD is rated at 4.2 in 1960. Electric furnace production grew from 13.5 million tons in 1959 to this year's estimated capacity of 14.4. The bessemer process dropped from 3.6 to 3.4, and open-hearth was 126.5 tons in 1959 and estimated at 126.6 at the beginning of 1960.

Comparing the two revolution makers, the oxygen converter process has grown from practically nothing to over 4 million tons in the last five years. This same level required about four decades for the electric furnace.

Direct Reduction, another way

A method for reducing iron ore directly into pig iron is in pilot plant operation at Swindell-Dressler Corp's Indianola, Pa., facility. In this so-called *Orcarb* process, the ore is agglomerated with carbon and flux, reduced in a rotary kiln, and then smelted in an electric furnace.

The pilot plant consists of a rotating 3x12 ft direct-fired kiln in which high-grade, fine ore or concentrate and flux are preheated to about 1100°F. This is followed by a mixing device in which the hot ore is mixed with −4 mesh high-volatile coking coal. Heated to 600° to 700,° the mixture is fed continuously into an unlined steel retort revolving at a peripheral speed of 80 to 90 fpm. In the retort, the coal becomes plastic, picks up the ore, is rolled into pellets, hardens to low temperature coke at about 950°F, and is discharged to the reduction kiln. Sensible heat in the preheated ore, supplemented by indirect heating through the shell of the retort, carbonizes the coal. Coking time in the retort is from 10 to 15 min.

Reduction of iron oxides, first to FeO and then to metallic iron, takes place in the rotating kiln under proper temperatures and in the presence of carbon. Reduction to metallic iron is accomplished by heating at 1700° to 1900°F for 1 hr or more. The reduction kiln is 2.5x20 ft and has a 6-in. refractory lining.

Among the advantages of the process is the fact that capital cost is less than half that of corresponding facilities, using the standard blast furnace. Production costs of the two are about the same. Another advantage is cited with the prereduction in the rotary kiln. Since the electric furnace charge has 80 pct of the total iron in metallic form, less than 1000 kw is needed to produce a ton of pig iron.

More LD developments

Pintsch Bamag A.G. of west Germany has been awarded a contract for two 100-ton capacity LD converters and ladle cars by the H. K. Ferguson Co., div. of Morris-Knudson Co., Inc. The converters, said to be the largest of the basic oxygen type in the world, will be erected at the Pueblo mill of Colorado Fuel & Iron Co. Erection and start-up is scheduled for late this year.

* * *

Reports from Spain state that Krupp-Renn and two other firms have granted Altos Hornos de Vizcaya a credit for use in installing an LD steelmaking plant. Two converters with a total annual capacity of 360,000 metric tons will be installed, with provision made for doubling the output.

* * *

Kaiser Steel Corp.'s oxygen steelmaking furnaces at Fontana, Calif., are producing individual heats 70 pct larger than the original design capacity. Each of its three LD vessels was initially expected to handle 65-ton heats; however, production today is consistently in heats greater than 110 tons.

Grow long Ge dendrites

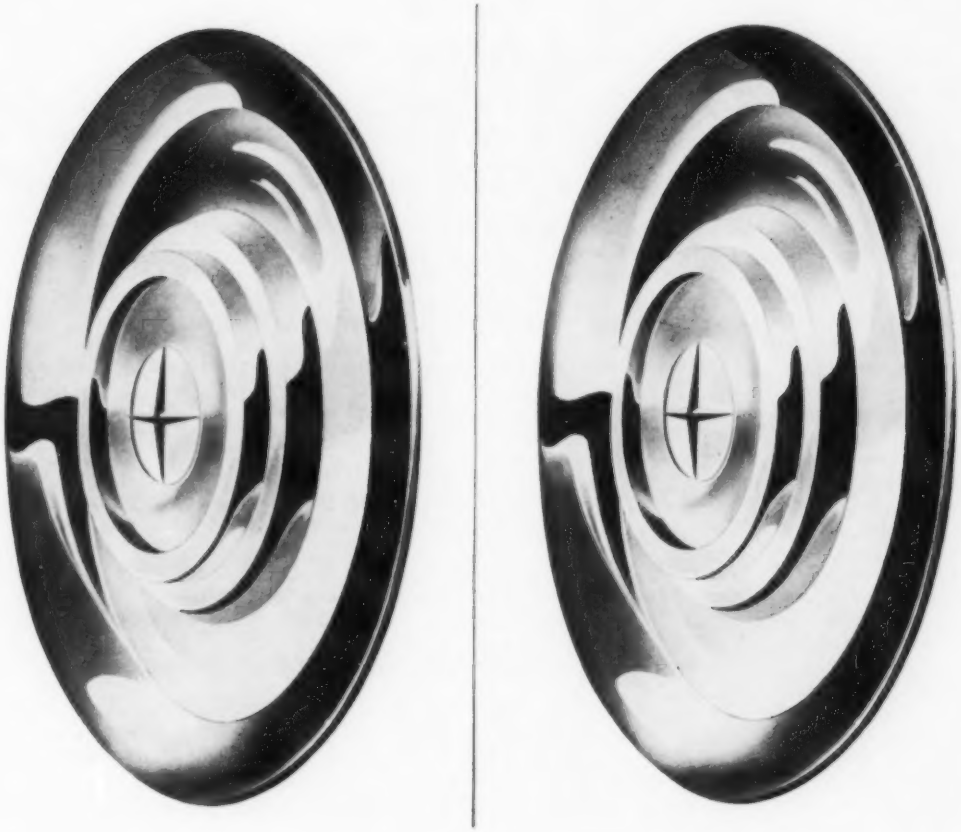
Manufacture of transistors and other devices by automatic machine is forecast as the result of a Westinghouse Electric Corp. method for growing long, thin dendrites of germanium.

The announcement by Dr. S. W. Herwald, vice president-research at Westinghouse, explains that, "This technique grows the germanium as thin, flat continuous strips, or dendrites—the exact form in which it can be used directly in finished semiconductor devices." Such construction appears to be feasible for the automatic production of transistors and other solid-state devices directly by machine. The development of such working devices from dendrites is being financed by a $2 million contract recently awarded Westinghouse by the Air Force's Air Research and Development Command.

Independently, metallurgists at Bell Telephone Laboratories have studied the basic mechanism underlying the growth of these germanium dendrites. They have demonstrated that the presence of two or more twin planes is an essential feature of each dendrite, and explained the unique shapes of the dendrites in terms of the way in which the twin planes affect the nucleation and growth of crystalline layers. Actually, this phenomenon, in a crude form, was demonstrated as far back as 1955 by Billig of the Associated Electrical Industries, Ltd.

During the AIME Annual Meeting's IMD-ISD Solidification session I on Wednesday, Feb. 17th, the first oral presentation of this new development will be presented, with papers by metallurgists from Westinghouse and from Bell Labs. The session will meet in the Ballroom of the Sheraton-Atlantic Hotel at 9 am that day.

Which hubcap would you reject?



MCA's RareMeT Compound minimizes surface defects

Deep drawing steels, extensively used in automobile production, are often rejected because of surface defects which, in turn, cause low yields. Only the best quality can withstand deep drawing operations and at the same time give high yields.

Our wide experience in numerous plants throughout the country has proven that small additions of RareMet Compound aid in the manufacture of these steels by increasing hot workability and reducing the size of harmful inclusions.

If increasing demands for better quality, through improved surface, play a part in your operations as a producer, the economical use of MCA RareMet Compound is strongly advised. A letter addressed to the nearest MCA office listed below will bring prompt and confidential response.

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TRANSACTIONS

OF THE METALLURGICAL SOCIETY OF AIME

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PERSONALS

(Continued from page 108)

Russel T. Drennan has become director of sales for Kaiser Refractories & Chemicals div. of Kaiser Aluminum & Chemical Corp. He was formerly general sales manager for Kaiser Chemicals.

Chester E. Grigsby is head of the Transportation Equipment div. of American Steel Foundries. With the company for 36 years, Mr. Grigsby is also a vice president and director there.

Barton Roessler is one of 35 fellowship recipients recently named by the National Science Foundation. The award is for study and research in the sciences under the Foundation's Postdoctoral Fellowship Program. Dr. Roessler, now at the Massachusetts Institute of Technology, will study at the Technische Hochschule, Stuttgart, Germany.

Frank R. Milliken, executive vice president and director of Kennecott Copper Corp., is heading a $1 million fund-raising campaign for the Foreign Policy Association. The Association's aim is to promote greater public understanding of world affairs.

Charles M. Hammond has joined the Allegheny Ludlum Steel Corp. as a senior research metallurgist. Dr. Hammond will work in the field of alloy development and applied research at the firm's Research and Development Center. Prior to joining Allegheny Ludlum, he was a research assistant at the University of Michigan Research Institute.

Phillip H. Smith, LaSalle Steel Co., served as moderator for a business communication workshop, part of a Purchasing Workshop sponsored by the Illinois Institute of Technology.

Clarence Thom is now the consulting metallurgist for Denver Equipment Co. His former position at Denver Equipment was that of director of the Company's Ore Testing div.

O. D. Rice has been elected president of Rust Furnace Co., Pittsburgh. Prior to his appointment he was general manager of the Company. **Frank A. Blaine,** his former assistant, has taken the post of general manager.

Richard P. Simmons is now manager of quality control for the Latrobe Steel Co. Before joining them, he was with the Titanium Metals Corp. of America.

Maurice J. Day is now vice president in charge of commercial activities at Crucible Steel Co. of America. The newly-created post carries with it the responsibility for sales management in the Company. He was formerly vice president of technology for the organization.

John Van Nostrand Dorr, inventor of Dorr metallurgical and sewage treatment equipment, heads the newly-formed New York firm of consulting engineers called Dorr Consultants. The firm will cater to chemical process, textile, and metallurgical industries by offering engineering, financial, and management services.

Robert C. Meissner has been named president of Meissner Engineers, Inc. Mr. Meissner was previously executive vice president of the firm and administrative officer for all projects in consulting and design.

H. A. Bednarski has been promoted to assistant manager of basic sales and hearth materials, Harbison-Walker Refractories Co. He has been with Harbison-Walker since 1956, joining them from U. S. Steel's South Chicago works.

Paul W. Beamer is now heading a newly-formed sales staff at Wyman-Gordon Co. which will work with exotic metals and alloys. His title will be manager of new products sales and development. Mr. Beamer was formerly in sales and marketing with Kelsey Hayes Corp.

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Joseph L. Gillson

AIME President, 1960

As President-Elect of AIME this past year, Dr. Joseph L. Gillson has been doing not one but three jobs for his profession and the Institute, besides his full-time job as chief geologist for du Pont. His first was as active board member and traveling emissary for the Institute; his second job was that of Co-chairman of the Member Gifts Committee of AIME for the new United Engineering Center. And, last but not least, editor-in-chief of the new third edition of **Industrial Minerals and Rocks**. His chores on this authoritative volume alone were enough to keep most men busy, since he worked personally with every step from manuscript to page proof.

Introducing Dr. Gillson as AIME's President for 1960 is almost superfluous, for, as one of the most travelled men ever to hold this office, he is on a first-name basis with a tremendous percentage of the members, not only of AIME, but of other groups in the mining and minerals industry.

After service with U. S. Navy during World War I he completed his education. Following early years of teaching at Harvard and MIT and field work with the USGS, he joined the du Pont Co., in 1929, and has continued there to this day. As geologist and later chief geologist, his travels for du Pont took him across most of the world in search for a long list of raw materials, including sulfur, titanium, fluorspar, manganese, and others. In 1940 he served as special geological adviser to the then state of Travancore in southern India.

More recently, he has been honored by AIME itself. As the 1957 Jackling Lecturer his topic was *A Geologist Looks at Industrial Minerals*, and the citation on the accompanying award read for "his significant contribution to the advancement of economic geology, his leadership, and his keen sense of professional responsibility."

Besides representing the Institute in many ways he has been particularly active in the Industrial Minerals Division of which he was Chairman in 1947. Since then he has been an AIME Vice President and Director in 1951-53 and 1956-59.

In other professional activities, his habits of intense work have resulted in several patents and the publication of more than 30 papers. A number of his papers have appeared in AIME Transactions. In recent years he has been widely known for his work and publications on titanium occurrences across the world, both in placer and nonplacer deposits.

A member of the staff who wanted to introduce him at a reception recently discovered after four tries with "Dr. Gillson" that he caught his attention more quickly if he murmured "Joe." It suffices to say that despite degrees, awards, honors, and the highest offices his professional colleagues could offer him, Dr. Gillson has retained a completely unpretentious outlook.

In selecting a President for 1960 AIME not only found a man who has already proved he can do three jobs at once, but the Institute also gained a first lady who has traveled almost as much as her husband. Dr. and Mrs. Gillson were married in 1918, and have three children and four grandchildren. As Dr. Gillson's constant companion Grace is already well known throughout AIME, and it is not completely said in jest that she keeps her suitcase packed and on rollers!—R.A.B.

Carleton C. Long

Metallurgical Society President, 1960

Carleton C. Long, director of research, zinc smelting div., St. Joseph Lead Co., is the 1960 President of The Metallurgical Society. Dr. Long will take office at the Annual Meeting in New York Feb. 14-18. He succeeds Dr. John Chipman, head of the Department of Metallurgy, Massachusetts Institute of Technology.

Dr. Long was the 1959 Vice President of The Metallurgical Society and is also a Director of the AIME. His many activities in the AIME date from the day he first joined the Society in 1937. Dr. Long was Chairman of the Lead-Zinc Committee in 1948 . . . one of the founders of the Extractive Metallurgy Division, and its Chairman in 1950 . . . Chairman, Metals Branch Council (1951) . . . AIME Director (1954-1957) . . . and Chairman of the Douglas Award Committee in 1956.

Professionally, his career has been with the St. Joseph Lead Co. He joined the company in 1935, just after receiving his doctorate from the University of Colorado. His first tasks with the Josephtown smelter of the zinc smelting div., Monaca, Pa., were as a research engineer. He was made director of the plant research dept. at Josephtown in 1937, and subsequently assumed his present post. His professional publications have dealt chiefly with the electrothermic winning of zinc and with the development of young engineers.

A member of many professional societies, Dr. Long is a former chairman of the Pittsburgh section, American Institute of Chemical Engineers. He also holds membership in the American Chemical Society, the Electrochemical Society, American Association for the Advancement of Science, American Society for Metals, Pennsylvania Society of Professional Engineers, and the National Society of Professional Engineers.

Division Chairmen of The Metallurgical Society

IMD

THOMAS A. READ

Dr. Read, head of the Department of Mining and Metallurgical Engineering, University of Illinois, brings a legacy of Institute of Metals Division activities to the office of its 1960 Chairman.

His first remembered activity was on the IMD Programs Committee in 1943. Later, he was Chairman of the AIME's Philadelphia section. From 1952 to 1955 he was one of the AIME representatives to the Engineers Council for Professional Development of the Engineers Joint Council. He has also served on the IMD Special Programs Committee, Publications Committee, and Executive Committee. He was Chairman of the IMD Education Committee several years ago, and is currently a member of the Executive Committee of the Council of Education.

Professionally, Dr. Read joined the Westinghouse Research Labs immediately following study for a Ph.D. in physics at Columbia University. He served Westinghouse from 1939-1941. From 1941 to 1947 Dr. Read was a physicist in the Ordnance Research Laboratory of Frankford Arsenal. The next year was spent with the Oak Ridge National Laboratory, and from here he entered teaching at Columbia University. The IMD Chairman was associate professor of metallurgy in the School of Mines at Columbia from 1948 to 1954. In 1954 he assumed his present post as head of the Department of Mining and Metallurgical Engineering, University of Illinois.

EMD

REINHARDT SCHUHMANN, JR.

Dr. Schuhmann is professor of metallurgical engineering and head of the School of Metallurgical Engineering, Purdue Universtiy. He has long been engaged in metallurgical education, teaching at the Massachusetts Institute of Technology from the time he received his doctorate there in 1938 and since moving to the Purdue faculty in 1954. Beginning in 1946, Dr. Schuhmann's teaching, research, and consulting interests have been primarily in extractive and chemical metallurgy. During World War II he collaborated with MIT's Prof. A. M. Gaudin, first in developing processes for beneficiating Bolivian tin ores, and later in the Manhattan project, by developing processes now used commercially for recovery of uranium from South African gold-uranium ores. Dr. Schuhmann and his graduate students are presently doing research on the thermodynamics of high-temperature metallurgical systems, concentrating particularly on copper smelting mattes and slags.

A member of the AIME since 1932, Dr. Schuhmann has participated in programs and committee work in all three divisions of The Metallurgical Society, as well as the Minerals Beneficiation Division of the Society of Mining Engineers. Through it all, he still considers the EMD his *home base*. He was also the first chairman of the Education Committee of The Metallurgical Society, and for the past two year's has been the Society's representative on the Education and Accreditation Committee of the Engineers Council for Professional Development. In 1959, Dr. Schuhmann shared the EMD Award for the best paper in the field of extractive metallurgy with William A. Krivsky.

ISD

JOHN J. GOLDEN

Mr. Golden is assistant to administrative vice president-production dept. U. S. Steel Corp. The new chairman of the Iron and Steel Division is a native of Chicago and attended the University of Chicago.

Mr. Golden first joined U.S. Steel in 1911 at its South works, Chicago. In 1933 he was made superintendent of #2 open hearth at the plant. From here it was transfer to the Gary works as superintendent of steel production. After two years in that capacity, Mr. Golden was made division superintendent of steel production. He held this position until 1950, when he was moved to Pittsburgh as assistant to the vice president-steel production. The AIME Division head was named to his present post at U.S. Steel in 1958. Another position he holds is that of chairman of U.S. Steel's operating committee for steel production.

Mr. Golden's history in the Institute included a term as Chairman of the National Open Hearth Steel Committee (1951-1952); Past-Chairman (1952-1953); and vice Chairman of the Iron and Steel Division (1956-1958). He is also a member of the American Iron and Steel Institute, American Society for Metals, and Association of Iron and Steel Engineers.

new books

Books that are marked (•) may be ordered through AIME. Address Irene K. Sharp, AIME Book Dept., 29 W. 39 St., New York 18, N. Y. A discount is given whenever it is possible.

Nuclear Irradiation Effects on Ferromagnetic Core Materials, by R. S. Sery and D. I. Gordon of the Naval Ordnance Lab, 72 pp., 1958—Reactor irradiation tests of the magnetic properties of 14 representative ferromagnetic core materials showed that designers of magnetic devices must be selective in choosing materials; certain types of high performance may be unattainable in radiation environments. Results, although based on one set of radiation conditions, indicated serious trouble spots. The highest permeability, lowest coercive force materials, such as Supermalloy and 4-79 Mo Permalloy, were degraded drastically by irradiation exposure. Materials, such as Mumetal, grain-oriented 50-50 nickel-iron, and 48 nickel-iron, also deteriorated appreciably, but to a lesser degree. Least damage was shown by the silicon-irons, aluminum-iron, and 2 V Permendur. Order *PB 151174* from the *Office of Technical Services, U S Dept. of Commerce, Washington 25, D. C.*

Considerations sur Le Module D' Elasticite et la Capacite D'Amortissement des Fontes Grises, by Elisabeth Plenard, *Technique des Industries de la Fonderie,* 166 pp., approx. $5, 1958—This French language book represents a dissertation on the modulus of elasticity and the damping capacity of cast iron. The author begins with a fundamental discussion of the elastic characteristics of cast iron and continues with a detailed description of several methods of measuring the modulus of elasticity and a comparison of the results obtained on various metals by the use of these methods. The influence of structure and the method of production on the modulus is considered, with special attention to the effect of graphite. •

Warmebehandlung der Eisenwerk Stoffe (Heat-treatment of Ironworks Materials), by Heinrich Ruhfus, *Verlag Stahleisen,* Dusseldorf, 483 pp., approx. $11.25 1958—This German-language text on the heat-treatment of ferrous materials is primarily intended to help the heat-treater or design engineer in selecting the best method and equipment for a desired quality. In addition to practical information on methods and installations, the book also covers the basic theory of iron crystal structure. •

Planung und Bau von Huttenwerken (Planning and Building of Steelworks), 2nd edition, by Friedrich Luth, *Springer-Verlag,* Berlin, 187 pp., approx. $6.75, 1958—Now in its second edition, this work, as the title connotes, deals with the planning and construction of metallurgical plants, including rolling mills. Examples of recent practice are cited, and tabular data flow charts of materials involved in different types of plants are included. •

Review of Metal Literature, 1958, edited by Marjorie R. Hyslop, *The American Society for Metals,* 1289 pp., $20, 1959—This volume includes brief abstracts of the published literature in the field of metals for 1958. The abstracts are designed to indicate the scope and content of the articles, rather than being informative. A complete alphabetical subject index is provided. •

Proceedings of the Third Conference on Carbon, 1957, *Pergamon Press,* 718 pp., $20, 1959—Papers included cover a wide range of topics, while broadly grouped into the following categories: benzene, graphite, and diamond; electronic properties; reactions and compounds; graphitization and structure; mechanical and thermal properties; and carbon technology. •

AIME PUBLICATIONS

Society of Mining Engineers does not plan any special volumes in 1960 however the **Third Edition of Industrial Minerals and Rocks** originally scheduled for 1959 will carry a 1960 copyright date and will be available for $8.40 to members and $12.00 to nonmembers. (An additional charge of 50 cents is made for each book mailed to nonmembers outside the US.

Society of Petroleum Engineers will issue a Volume in two parts entitled **International Oil and Gas Development.** This Volume replaces the Statistics of Oil and Gas Development and Production and will be published jointly with the International Oil Scouts Association. Part I covering Exploration is to be released in June and Part II, Production, is to be released in October.

Elements of Petroleum Reservoirs a 300 pp. book by Norman J. Clark is expected to be published in March. Price to members will be $4.90; $7 to nonmembers. (An additional charge of 50 cents is made for each book mailed to nonmembers outside the US.

Waterflooding a 200 pp. booklet of papers previously published in Petroleum Transactions is to be issued as Petroleum Transactions Reprint Series, No. 2, $2.50, now available. No discount to members.

The Metallurgical Society will, as usual, publish the Conference Proceedings for the three Iron and Steel Division conferences. These are: **The Open Hearth Proceedings, The Electric Furnace Proceedings,** and **The Blast Furnace, Coke Oven, and Raw Materials Proceedings.** These are available to members for $7; $10 to nonmembers. (An additional charge of 50 cents is assessed for each book mailed to nonmembers outside the US.

TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME. Member's subscription is $5. Additional subscriptions are available at $20. Nonmember rate is $20 in North, South, and Central America; elsewhere $25. Several other volumes are planned and will be announced at a later date.

TRANSACTIONS VOLUMES

No.	Society	Members: Pay with Dues	Members: Pay Later	Nonmembers: North, South & Central America	Nonmembers: Elsewhere
214	Soc. of Mining Eng.	$3.50	$4.90	$ 7.00	$ 7.00
215	The Metallurgical Soc.	5.00	5.00	25.00	30.00
216	Soc. of Petr. Eng.	3.50	4.90	7.00	7.00

Note: 1959 bound TRANSACTIONS volumes to be issued in 1960.

1960 JOURNALS

Name	Members (One Journal With Dues): Other Journal	Members (One Journal With Dues): Same Journal	Nonmembers: North, South & Central America	Nonmembers: Elsewhere
MINING ENGINEERING	$4.00	$8.00	$ 8.00	$10.00
JOURNAL OF PETROLEUM TECH.	4.00	8.00	8.00	10.00
JOURNAL OF METALS	4.00	8.00	10.00	10.00

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The purpose of friction research at the GM Research Laboratories is to learn more about the elastic and inelastic behavior of materials. This knowledge – of academic interest now – will eventually give GM engineers greater control of energy lost through friction. This is but one more example of how General Motors lives up to its promise of "More and better things for more people."

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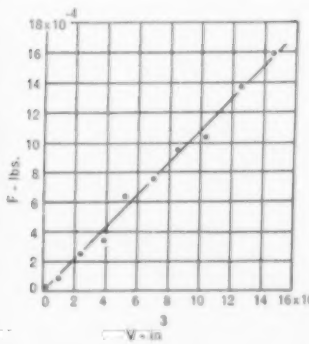


Relationship of rolling force to elastically stressed volume.

TITANIUM vs STEEL,

A Symposium

Organized by

R. I. Jaffee,

Program Chairman,

IMD Titanium Committee

THE Titanium Committee of the Society's Institute of Metals Division has arranged symposia for the Fall Meeting for the past several years. Originally, the symposia dealt exclusively with various aspects of titanium technology and applications. However, titanium does not exist in a world of its own. Indeed, the rivalry of titanium vs steel for the applications of the metal is one of the keenest in metal marketing. Hence, at the most recent symposium, in Chicago on November 3, 1959, the broader question of the competitive position of titanium vs steel was taken up.

The symposium was organized to permit speakers representing the producing industry and users to present the cases for titanium and for steel in various applications important in titanium usage: airframes, jet aircraft engines, pressure vessels, solid fuel motor cases, and chemical equipment (in the latter application all materials competitive with titanium were considered). Each speaker was provided with the opportunity for a brief counter argument, after having heard the formal presentation for the alternative material. The time remaining for each of the cases considered was taken up with discussion from the floor.

Dr. W. J. Harris, Jr., Director of the Materials Advisory Board, National Academy of Sciences, was moderator of the symposium, and to him belongs much of the credit for the lively and informative discussion periods following the formal presentations. As was true for previous IMD titanium symposia, the audience contained many who were particularly informed. Dr. Harris skillfully directed questions to them and drew their discussions.

The formal presentations at the Titanium vs Steel Symposium are given in the following sections:

Introduction	W. J. Harris, Jr.
The General Case	
Titanium	W. W. Minkler
Steel	R. B. Gunia
Airframes	
Titanium	E. A. Simkovich
Steel	E. A. Green
Jet Engines	
Titanium	G. J. Wile
Steel	R. W. Patsfall
Pressure Vessels	
Titanium	A. Hurlich
Steel	J. F. Baisch
Solid Fuel Motor Cases	
Titanium	J. Sohn
Steel	D. K. Hanink
Chemical and Marine	
Titanium	G. R. Prescott
Other Metals	F. W. Fink

No verdict was reached at the Titanium vs Steel Symposium, and the debate no doubt continues in the minds and councils of the users. Perhaps the material presented will help the readers of JOURNAL OF METALS *come to a decision for their own applications.*

R. I. JAFFEE is with the Battelle Memorial Institute, Columbus, Ohio. This symposium was presented at the 1959 Fall Meeting of The Metallurgical Society.

INTRODUCTION to the Symposium

by W. J. Harris, Jr.

of the Materials Advisory Board

During the past 10 years, we have seen a unique development in the materials structure of our economy. We have observed the creation of an industry to provide for high-temperature, high-strength, metals for defense applications. One approach was based on titanium, an element that was considered only a laboratory curiosity in metallic form until 1947. Prior to that time the development of strength properties in steels was restricted to laboratory samples with a very small production basis. These developments have not been easy from a technical or financial standpoint; nevertheless, they have been accomplished to the point that designers have more frequently than ever before urged the selection of new materials in the design of high-performance components.

There have been several interesting sidelights in the development of these new materials that are worth mentioning. Titanium has been developed under Government funding, with at least two new identifiable administrative approaches. In the first place, the organization of a program for supporting the production of raw materials has led to new views toward the administrative relation between Government and basic industry. Secondly, the requirement for effective dissemination and evaluation of the vast quantities of research data furnished to Government through direct or indirect support required the establishment of the Titanium Metallurgical Laboratory. The Laboratory issued reports based on both published and unpublished data. This administrative invention has now been extended to other materials—again to the ultimate benefit of both producer and user.

In regard to steel, the most important finding has to do with the fact that we now know that limitations in the performance of the metal (imposed by the deficiencies in a particular quality) are often eliminated by careful research and development. That steels could be made with strength levels up to 300,000 psi has been known for many decades, but the ductility of these steels was so low as to suggest very limited applications. However, effective research and development on processing and heat treatment yielded important information that was translated into high-strength steels with usable amounts of ductility.

Commercial opportunities once opened to titanium have been seriously restricted by the development of steel. Availability of titanium has led the steel producers to intensive and costly research and development that may not be recovered from product sales for many years.

Neither industry is entirely happy at the symptoms of growth of the other. The group that benefits from the producers activities, however, is the vast and complex using industry. Technological competition between other materials of the kind represented by that between steel and titanium will continue and be extended as adequate programs of research and development on materials are supported.

THE GENERAL CASE

TITANIUM

by Ward W. Minkler of Titanium Metals Corp. of America

In comparing the relative advantages of these two structural materials, the first question is:

Does titanium have any particular structural condition where it alone can fulfill a need which at least one of the host of steel alloys cannot?

With the exception of a few isolated examples—largely confined to chemical processing equipment and electronics—the answer at the present time has to be, no. Jacketed in steel, the airplane would fly and the missile might take off. Perhaps the airplane would consume more fuel, require a larger power plant, and be subject to more frequent maintenance; perhaps the missile payload might have to be more *miniaturized*. But the fundamental purpose of the structure could be fulfilled.

Why then should we look further? There is only one reason: the benefit to be accrued through increased efficiency and integrity of the lightest structure required for an assigned design function. This is the same reason underlying the development of higher strength steel, aluminum, and magnesium alloys.

To compete effectively with steel, titanium must exhibit one or more characteristics that will improve the efficiency of each unit weight of the structure. To spell out some of the reasons why titanium can offer these efficiencies let us assume, for the time being, that there is no price differential between steel and titanium. The importance of section size, as introduced by moment of inertia or radius of gyration in determining safe loading of structural members, is readily recognized. Since the dimension of section size is either area or volume, the advantage of low-density material is not a linear function, but more frequently a squared or cubed function. This, of course, has been well recognized by aluminum and magnesium producers. But the fact must also be emphasized that the density of titanium is approximately 38 pct less than steel.

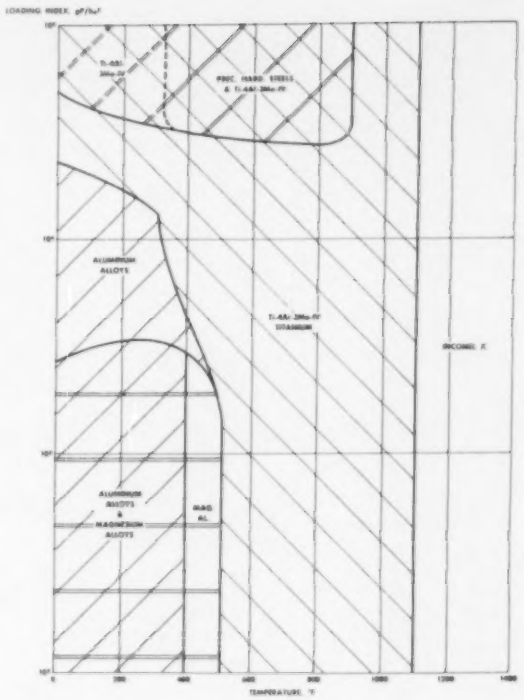
More sophisticated analyses have been provided by Jackson and Gordon of Battelle and Prof. Gerard of New York University.[1] Both of these analyses illustrate the superiority of titanium alloy structures, over a comparable steel, in explicit loading over the range of temperatures in which the two materials might be considered competitive.

Unfortunately, factors other than the relatively straight-forward calculation of load carrying capacity frequently determine the ultimate capability of a structural member to perform its function reliably. Such factors as ability to withstand unanticipated shock loading . . . fatigue characteristics . . . sensitivity to notches . . . freedom to withstand unusual or unanticipated temperatures . . . and freedom from structural degradation due to corrosion are generally of equivalent importance to calculated load-carrying ability in a reliable structure.

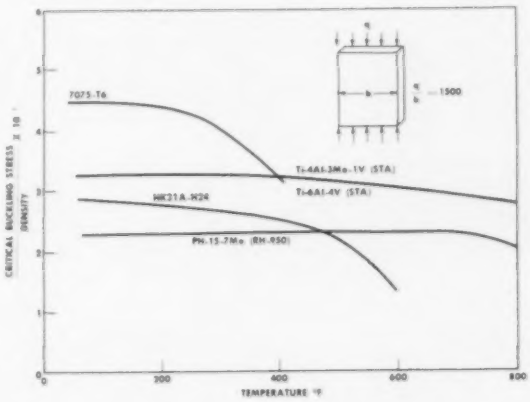
Performance reliability

The only true test of the performance reliability is historical record. Performance reliability of titanium structures may well be one of the metal's strongest attributes in its competition with steel as well as other structural metals. Only now is sufficient service time being accumulated to judge the sustained functional integrity of titanium structures. The fact is that, after the elimination of hydrogen embrittlement, the performance record of titanium aircraft structures has been exemplary. Such statements as "Except for the hydrogen problem in 1954 and 1955, no service-reliability problems with titanium have been reported" and "over 1,000,000 flight hours of service time have been accumulated with no reports of failure of any titanium compressor parts," are significant evidence, particularly in applications where design allowances must contain a minimum of excess fat.

While this is, no doubt, due in part to rigid material specifications and fabrication surveillance, two other factors appear to be of basic importance: the general chemical inertness of titanium, even when highly alloyed; and structural independence of a wide range of operating environments. The best illustration of this latter factor is that in our program today one single titanium alloy, Ti-6Al-4V, is a basic structural material for efficient airframe missile or engine parts operating up to 800°F. This same titanium alloy is the basic structural material for minimum weight pressure vessels operating at −320°F. This one titanium alloy can seriously challenge a host of steel alloys, by comparison of restricted environmental application, if structural efficiency and integrity are considered the basic criteria.



Above, variation of loading index with temperature for several alloys. Below, relative efficiencies of aircraft materials under compression panel loading as a function of temperature.



Economics considered

Leaving the area of technical considerations as a function of inherent material characteristics, we must then enter more controversial areas. This area should include availability, fabricability, design knowledge, cost vs anticipated value received, and merchandising aggressiveness. Each of these influences the material choice.

Perhaps **availability** is the least troublesome of all problems confronting titanium. For a metal to be seriously considered at any given time, it must be readily available in the form and quantity required by the designer. Implicit in availability is natural occurrence in reasonable concentrations. Here the proven abundance of titanium in the earth cannot be overlooked as a positive factor in its future. As our

expanding population depletes our resources, natural abundance will become an ever-increasing economic factor.

Beyond ore supply, then, availability becomes a human and controllable factor. We have found nothing, with respect to mill product size or shape, that would preclude the manufacture of the same product in titanium as is available in steel. In wrought products, with the now-developed continuous cold rolling of alloy strip, the limitation is confined solely to size of mill equipment, the same basic equipment used to produce steel. In some instances, the manufacturing techniques have not been as refined as in steel, but based upon current knowledge, no inherent characteristic of titanium would discount the employment of rather simple forging, rolling, or extrusion operations.

Fabrication, like mill processing, is again a matter of human control. For example, it was not so many years ago that the most common complaint about titanium fabrication was its *unmachinability.* One of the most positive indications of the temporary nature of such problems was a recent incident in which a fabricator switched from type 422 steel alloy to a titanium alloy, Ti-6Al-4V, because the machining costs of steel compared to titanium exceeded the material price differential. The same type of comparison can be made in sheet fabrication of high-strength, solution-treated alloy titanium as opposed to the precipitation-hardened steels. One of the greatest difficulties in the effective comparison of titanium formability has been the fact that titanium formability comparisons have initially been based upon results obtained with equipment designed for the other metal. The relative ease with which titanium has been hot formed, flow turned, and forged in equipment specifically designed or modified for titanium is evidence of the temporary nature of this consideration.

The problem of designers' knowledge of titanium and their confidence both in the material and in their ability to use it most efficiently is probably the greatest single obstacle yet to be overcome by the titanium advocate. The appreciation of titanium as a workable, functional, reliable, structural material is only now in an incipient stage. When one considers the multitude of handbooks, design manuals, specifications, and background experience available for competitive materials, compared to the miserly supply of titanium design information, the problem is well recognized. I know of no answer to this problem other than time, patience, and a large technical publications budget.

Certainly in any discussion of titanium as a competitor to steel, the general subject of dollar economics cannot be ignored. No matter what the potential application, the use of titanium must result in an ultimate economic advantage, either by lower initial cost or long-range operating efficiencies, in order to offset any price differential.

While **price** competition is titanium's most immediate serious disadvantage, it may well be the most transitory and controllable. This extrapolation is based upon two major points. During the past three years the price of most titanium mill products has been reduced as much as 50 pct. This was despite the fact that during the period the industry was operating at a fraction of its capacity, yet confronted with the normal primary metals industry characteristics of high fixed capital investment per unit of product. What might have been the effect on cost—consequently on price—if we had been able to amortize these fixed charges on full capacity?

The second major factor favoring the lightening of titanium's economic burden, is increasing recognition of the advantages to be incurred through the design of maximum efficiency structures. The trend, inspired by the rigid demands of aircraft, is only in its formative phase. We can expect increasing recognition that unnecessary weight and high maintenance in mobile or even many fixed structures is often wasteful. Elimination of unnecessary structural weight can lead to operational economies, even if initial costs are higher. Design compromises necessary because of unsophisticated or relatively inaccurate raw materials will meet with increasing market resistance in the future. The raw material's manufacturer will be required to supply a more accurate starting product. Hence, we see the trend toward vacuum melting, closer tolerances, and ever-tightening quality restrictions, even in the steel industry. The titanium industry was born and has been nurtured in the environment of precise aircraft specifications, thus the effect of this trend on titanium's manufacturing cost is minor. The effect on production costs of other structural raw materials may well be somewhat more drastic.

In conclusion, then, titanium will compete with steel only where it is the structurally more efficient material. It will be so on the basis of lower density, natural abundance, and relative insensitivity to operating environment. Given these basic attributes the effectiveness of competition will then depend upon industrial courage and marketing ingenuity.

[1]L. S. Jackson and S. A. Gordon: *The Application of a New Structural Index to Compare Titanium Alloys with Other Materials on Airframe Structures,* Report no. 24, Battelle Titanium Metallurgical Laboratory, Columbus, Ohio, Dec. 1, 1955.

George Gerard: The Crippling Strength of Compression Elements, *Journal of Aeronautical Sciences,* 1958, vol. 25, p. 37.

CASE FOR STEEL

by R. B. Gunia of U. S. Steel Corp.

During the past five years much has been said and written about the types of materials that will be required for construction of high-speed aircraft and missiles. It is often stated that advanced designs are already being limited by the non-availability of suitable materials.

Early last year, Wernher Von Braun listed the following structural requirements for current missile and aircraft systems: 1) ultimate strength to weight ratio; 2) relative ease and reliability of fabrication; 3) availability of sheets and shapes; 4) strength at elevated temperatures; 5) strength at sub-zero temperatures; 6) erosion resistance; 7) corrosion resistance; 8) aging characteristics; and 9) nominal cost. Dr. Von Braun also stated, "We cannot design functional missiles, satellites, and space vehicles on the basis of properties of laboratory curiosities."

N. E. Promisel of the US Navy Bureau of Aeronautics has indicated that several groups of steels are under active consideration for application in advanced hypersonic aircraft, missiles, and rockets. Steels having tensile strengths in the range 260,000 to 280,000 psi are already in use, and newly developed steels exhibiting strengths in the 350,000 to 500,000 psi range are beginning to appear.

L. P. Spalding of North American Aviation has stated that steel was selected for use in the construction of the B-70 and the F-108 because it offered some important advantages over other possible materials. He said steels are available, cheap, strong, formable, weldable, and brazeable, and that some of the steels are corrosion resistant and have good strength at moderately high temperatures.

Mr. Spalding predicts that supersonic manned aircraft will continue to be useful for many years, and that the performance and design of military craft of today and the commercial transports of the late 1960s will be such that steels are likely to be the predominant structural materials. These will be used principally in thin gage sheets of alloy and stainless steel produced to exacting specifications.

According to the Aerospace Industries Association, it is the consensus of the industry that steel will be one of the predominant materials of construction for airborne vehicles during the next decade.

The steel industry, of course, is pleased with these statements and predictions. Steels that can render service competitively with other materials in that portion of the thermal spectrum ranging between 400° and 1200°F are now available or under development. It should also be noted that few materials can compete with stainless and alloy steels in sub-zero service.

Desirable properties

Now let us look at the desirable attributes of steel as outlined by the authorities mentioned.

Steels possessing high strength to weight ratios are currently available. Such alloys as SAE 4340, Cold Rolled Type 301, PH 15-7 Mo, and H-11 die steel are being used in missiles and aircraft now in production.

Steels currently in use are meeting the requirements of fabrication ease and reliability. These units are being drawn, spun, forged, welded, and machined. Techniques for welding steels containing 0.40 to 0.50 pct C have been developed and are being constantly improved. Missile motor cases in H-11, SAE 4340, Airsteel X-200, MBMC #1, and 300M are in production using these methods.

Steels now being used or evaluated are available in sheets and shapes. Rolled or extruded bar sections can be obtained. Forging billets, plates, and wire are being produced.

Many of the steels currently employed possess corrosion resistance better than that of competing materials. Some of the steels being studied, like many of the competitive materials, will require protective coating or cladding if they are to be useful in certain applications.

A number of the steels such as the PH group, AM 350, AM 355, and Stainless W, possess desirable aging characteristics.

Most of the steels being evaluated or used do retain a great measure of their room-temperature strength at moderately elevated temperatures. These steels are, at present, equal to or better than competitive materials in the 400° to 1000°F range. Steels under development will probably extend that range to 1200°F. It may be possible to develop ferrous alloys that will be serviceable up to 1500°F. Beyond that temperature, we do not believe steels will be useful in high-strength designs.

All of the steels we have mentioned are available with a high degree of quality, uniformity in composition, and mechanical properties. Thus, they have the capacity for reproduction at predicted strength levels.

The steel industry has been criticized by some for its conservatism. It has been chided for lack of interest in the materials procurement problems of the aircraft industry. Yet all of the steels we've mentioned were developed by the steel industry. Sheets 10x30 ft in a wide variety of gages and in a number of compositions are now available. Sheets of 36 in. width with a tolerance of ± 0.001 in. have been produced. These are only a few examples of the things our industry has done despite a lack of knowledge of the size or even the specific requirements of the market. This is hardly evidence of conservatism, disinterest, or refusal to consider the material problems of the aircraft manufacturer.

Much yet to be done

As reports originating from various sources in the aircraft industry come in, the steel industry is becoming keenly aware of the challenge to develop new and unusual ferrous alloys. This challenge goes much deeper in that the compounding of new and unique high-strength, temperature-resistant alloys is only the first step and often the least expensive. As Dr. Von Braun stated, alloys that show promise in the laboratories can be used only if they can be converted to useful raw material for further conversion and fabrication. To accomplish this objective and convert such materials to the product forms and high qualities demanded, the industry must make major investments in time and money.

Availability and economics

Steel has one advantage, often overlooked. It is available from a great number of sources and is produced in large tonnages. Thus, the consumer is often able to secure products in steel with much more success than he would be able to purchase competitive materials. Also, hundreds of shops which employ highly skilled and trained craftsmen with many years of experience in steel fabrication are in operation throughout the country.

Conclusions

In summary, stainless and alloy steels possess many of the attributes required by the aircraft designer. Such steels are capable of developing the high strengths needed. They can be bent, formed, drawn, spun, forged, welded, brazed, and machined. Fabricated components have a high degree of reliability. These steels are available in sheets and shapes. They retain their strength at moderately elevated temperatures. They are strong and ductile at sub-zero temperatures. They exhibit good resistance to corrosion and erosion. Several kinds of steel display desirable aging characteristics. And, finally, these steels are available from a large number of sources.

This, then, is the general case for steel.

AIRFRAMES, TITANIUM

by E. A. Simkovich of Republic Aviation Corp.

It is obvious that any manufacturer must utilize the best material, from an all-around viewpoint, for a specific application. However, a considerable amount of high-temperature structural development experience over the past decade has indicated that certain titanium alloys are the ideal materials for hot (up to 800°F) long-life, manned airplanes.

Historically, work at Republic first started in 1949, when an engine shroud was fabricated from commercially pure material. This component was installed in an F-84E airplane and was, it is believed, the first piece of titanium *hardware* to fly. During 1950, design studies were commenced on a radically new weapon system, the XF-103 interceptor. Parametric analyses at that time indicated quite clearly that the maximum performance could be obtained only through the use of titanium sheet and bar alloys in the main structure. The decision to design in titanium was made even though these alloys were only in their infancy.

The F-103 - a pioneer

The mission for which the F-103 was designed clearly indicated the necessity for a high *dash* capability coupled with high maneuverability. These two factors led to the imposition of extreme temperature and load criteria. Preliminary designs indicated an airplane weighing approximately 34,000 lb fully loaded. Of this total gross weight, about 12,000 lb were titanium. General skin temperatures reached 600°F plus, since the vehicle would operate well above Mach 2.

Structural materials were required to withstand the following conditions: 1) 1 hr at 600°F + at 2/3 of the tensile ultimate (limit load) at temperature; and 2) 400 hr 600°F + at 1/3 of the tensile ultimate at temperature.

Many components were critically loaded at relatively low temperatures, so that strengths after low-stress exposures were also a design factor.

Construction was conventional (i.e., sheet-stringer multi-spar heavy plate), since titanium sandwich was not available. The alloys utilized throughout were the 8 Mn sheet, the 4 Mn-4 Al bar, and 5 Al-2.5 Sn sheet and bar. Some 6 Al-4V was programmed into the vehicle in the later stages of design. The first airplane of the three originally contracted for was scheduled for completion by the middle of 1958. Unfortunately, the entire program died in the mass cancellation that resulted from the austerity program adopted in late 1957.

Testing and fabrication experience generated during the XF-103 program showed that an all-titanium airplane could be designed and built to efficiently carry out a complex, high-reliability mission with a considerable degree of confidence.

Fig. 1 illustrates the relative structural efficiencies of various methods of construction, as related to an imposed compressive loading without accounting for the properties of any specific material. It shows the sandwich type of construction, more particularly the honeycomb sandwich, to be the most efficient, weightwise, at the lower load intensities. However, also shown is the fact that at some higher load intensity, the more conventional types of construction become competitive and in fact surpass sandwich. If material properties of titanium vs stainless steel were integrated into a comparison of this type, the intersection points of the titanium construction curves with the stainless steel sandwich curve would be shifted considerably to the left. It also goes without saying that a honeycomb sandwich-type construction in titanium would far surpass anything else presently available.

Design factors

Taking a supersonic transport or bomber and analyzing materials capabilities as related to weight, we arrive at the *penalty* curves of Fig. 2. These illustrate the weight penalty that must be absorbed when designing to high-temperature requirements as compared to designing a room-temperature airplane fabricated from aluminum. The curves clearly indicate that titanium structures are far superior, up to at least 800°F, for the design criteria noted on the curve.

The basis for the weight changes shown is an equivalent room-temperature 7075-T6 aluminum structure. The study which produced these results considered a number of factors which, in the practical sense, influence the weight picture. Allowable strengths in tension and compression, as well as shear, were pro-rated according to the approximate degree of usage of these types of load carrying members in typical aircraft. The influence of various types of compression members, i.e., columns, plates, and plate elements, was similarly pro-rated. In compression, the intensity of loading was varied from low to high levels. The influence of load intensity is shown in Fig. 2 by the width of the curve band for each material. Consideration was also given to the fact that for many vehicles the maximum loads and temperatures do not occur simultaneously. Thus, the strength at temperature and the strengths at essentially room temperature were also pro-rated.

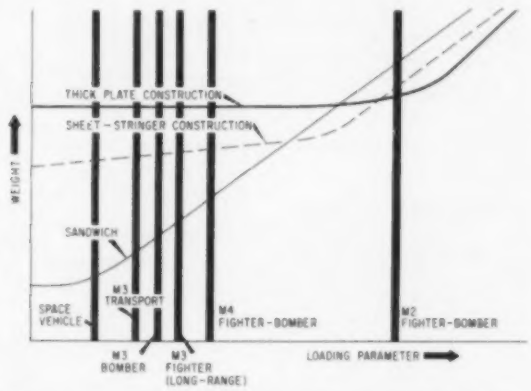
A considerable amount of experience has been accumulated over the past few years on the F-105 speed brake doors. The external skins operate at about 600°F at stress levels of approximately 60,000 psi. Titanium (8 pct Mn) door components have had roughly 230 hr of trouble-free service; there

has not been a single failure in over four years of test and service. This service record is indicative of the reliability that may be obtained from titanium when properly utilized.

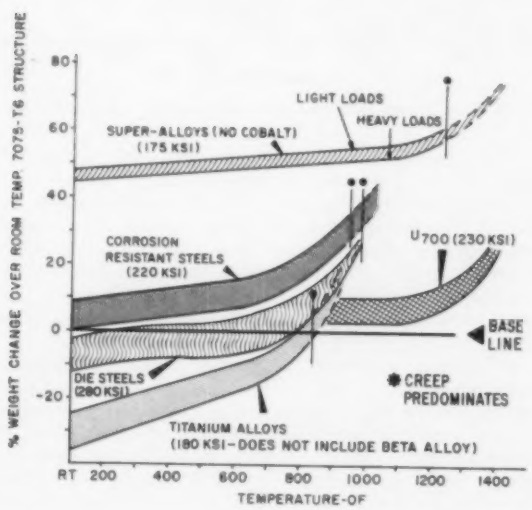
Summary

To sum up, the preceding discussion tends to reinforce the belief that, theoretically at least, titanium alloys are superior to any other generally available structural metal. One might rightly ask why it appears to have taken somewhat of a *back seat* position to corrosion-resistant steels. There are many factors involved, some of which are quite apparent, others which are not. However, these *defects* are not inherent in titanium, but arise rather from other considerations: economy, timing, and so on.

Whether titanium will ever be used in major structural applications for manned aircraft is a moot point. The rapidly accelerating technology of competitive weapon systems, combined with strategic tactical consideration, may well result in almost complete abandonment of some concepts. It is quite difficult to forecast the future. Strictly tactical airplanes and logistic or transport vehicles still appear to be desirable. If these operate at high temperatures, (say up to 800°F) titanium will certainly be quite strongly considered as the major constructional material.



Above, loading parameters vs relative weights for various flight vehicles. Below, weight penalties vs temperature for a large weapon system.



STEEL IN AIRFRAMES

by E. A. Green

of Lockheed Aircraft Corp.

Transports with speed capabilities of Mach 3 and beyond appear to be the next logical step in the improvement of manned aircraft. Lockheed has considered a typical transport of this type in which a new set of design conditions must be met by improvements in existing materials or the development of new materials. Although many new alloys of steel and titanium are being considered, further development is necessary to provide thoroughly satisfactory structural materials. To properly evaluate the applications, the operating environment must be known.

Because of their high speed at an average cruising altitude of around 70,000 ft, the new transports will be subjected to high skin temperatures from the air friction in flight, and must also continue to operate at normal ambient temperatures.

Fig. 1 indicates the broad range of elevated temperatures which will be encountered on the fuselage of a typical airplane. It should be noted that these range from approximately 520° to 420°F, and that there is a temperature gradient around the structure due to the airplane altitude. Typical temperatures for a wing range from nearly 600°F to as low as 320°F and also vary from upper to lower surface. An examination of the available materials indicates that no one material is most satisfactory for all applications in an airframe.

Design criteria

An evaluation of potential materials must be based on the range of temperatures to be encountered and must include all of the necessary design parameters which will determine the material usage. These include the ratio of tensile strength to density . . . compression yield strength to density . . . modulus of elasticity to density, buckling and crippling criteria, metallurgical stability, corrosion resistance, and such properties as tear and fatigue resistance.

Basic engineering properties must also be supplemented with an analysis of producibility considerations, including methods of fabrication and assembly, cost, and availability of the materials. For the purposes of this discussion, comments are being limited to two titanium alloys, 6Al-4V and the all-beta alloy, B120VCA, and to two steel categories, 5 pct chrome steels and precipitation-hardened corrosion-resistant steels.

Evaluation of material applications

When considering the tensile strength:weight ratio of various materials at elevated temperature, as shown in Fig. 2, it appears that the 6Al-4V and the B120VCA titanium alloys provide the lightest structure (by a very small margin over the 5 pct chromium tool steels) for tensile applications in the operating temperature range. It should be noted

that in purely tensile applications the precipitation-hardened steels, AM350 and 17-7PH, would show a weight penalty. The dotted line is the room-temperature value for 7075T6, a standard airframe structural material of today. It is included to allow a comparison with the high-temperature materials.

In considering the compressive yield strength as shown in Fig. 3, a titanium alloy, 6Al-4V again appears to be the most satisfactory in the specified operating range. However, Thermold J, a 5 pct chrome steel, appears to be somewhat better than the B120VCA titanium alloy. Here again the 7075T6 room-temperature value is shown for comparative purposes.

Design of wing box beams and some other areas is often determined by stiffness rather than strength. In Fig. 4, the modulus of elasticity:density ratio is plotted against temperature. It can be seen that the titanium alloys are very much poorer than the steels over the complete temperature range. This would indicate that steel structure is always lighter than titanium structure where stiffness is the design criterion.

The effect of temperature on elongation is a vital consideration in the choice of a structural material. If a material shows a marked decrease in elongation after exposure to operating temperatures, it may mean that it is metallurgically unstable. If it is unstable and becomes embrittled due to temperature effects, it will not meet the loading requirements of a transport aircraft which must have a long structural life. Elongation is particularly important in tension applications because holes, cutouts, and so on produce high localized stresses which can result in failures in materials with poor elongation.

Fig. 5 shows the change in elongation caused by holding materials at elevated temperatures. In this case the material was tested at room temperature before and after exposure. There is a marked reduction in the elongation of B120VCA titanium alloy and the slight improvement in the 6Al-4V titanium alloy. This curve is unrealistic for some applications, because the materials were not loaded during the exposure to elevated temperature.

Fig. 6 is presented to indicate the effect of load on the same materials. In this case, a stress of 25 pct of the hot ultimate tensile stress was applied to the material at temperature. Subsequently, the material was retested at room temperature. In the case of B120VCA, a broad scatter is apparent; therefore, it is obvious that substantially more development is necessary on this material. In this case also, the 6Al-4V titanium alloy drops off in elongation, and AM350 is unaffected. This information is not now available for the 5 pct chrome tool steels.

Tear resistance of many materials at elevated temperature is also being investigated, but valid information is not yet available.

Structural design approach

To properly evaluate the structure of a new airplane, a structural philosophy for the basic portions of the airplane must be established. In approaching these high-temperature airframes, Lockheed has elected to evaluate thoroughly the conventional types of structure. These conventional structures can be made competitive with the newer structural core designs in most applications, and they are substantially more producible. Where brazed honeycomb or other core configurations prove most effective considering the strength, weight, and cost criteria, they will be used.

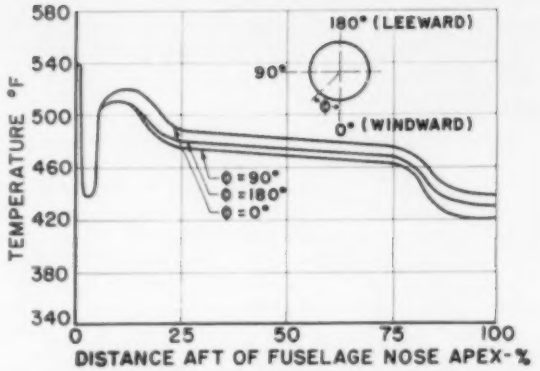


Fig. 1—Mach 3 transport, steady-state surface temperature along fuselage at 5° angle of attack, cruising at 70,000 ft.

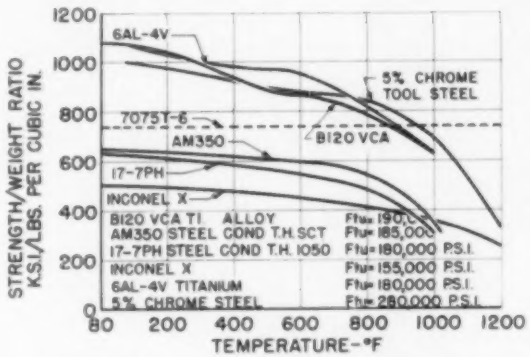


Fig. 2—Tensile strength:weight ratio of sheet materials.

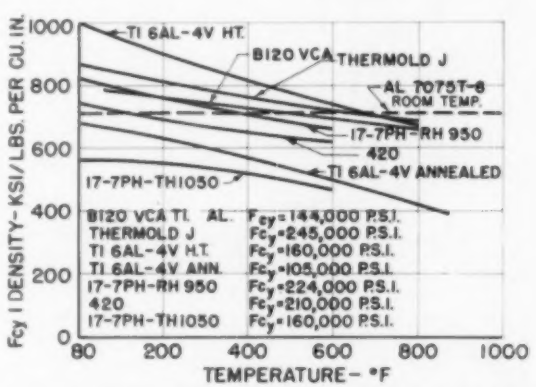


Fig. 3—Compression yield strength:density ratio of sheet materials.

Considering this general type of structure, the titanium alloys appear to offer a slight weight advantage for a high-speed airframe as illustrated in Fig. 7. Using this for a structural weight comparison we find that titanium can save approximately 4800 lb in an airframe of the type being considered. This weight was saved in areas such as wing trailing edge, wing tip, empennage, fuselage structure, and in the nacelle structure.

It should be noted that in the major structural components such as the wing box beam, weight savings were not possible using titanium because of the very much lower stiffness:density ratio at all temperatures. Engine intake ducts must also be made of steel, because operating temperatures are too high for the present titanium alloys.

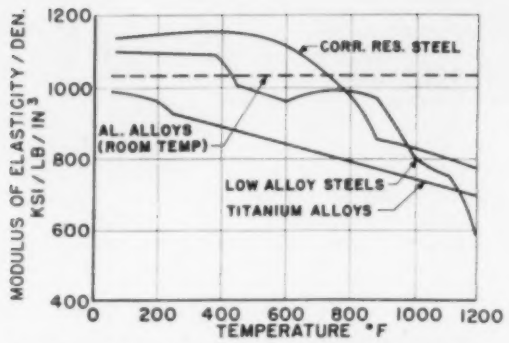


Fig. 4—Modulus of elasticity:density ratio of sheet materials.

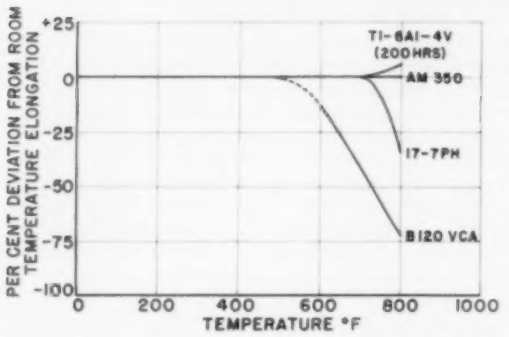


Fig. 5—Storage stability of steel and titanium alloys at 300 hr exposure time.

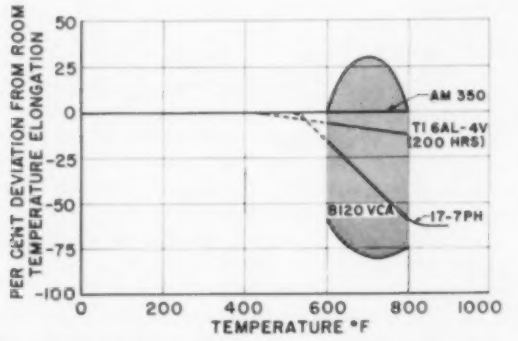


Fig. 6—Creep stability of steel and titanium alloys at 300 hr exposure time.

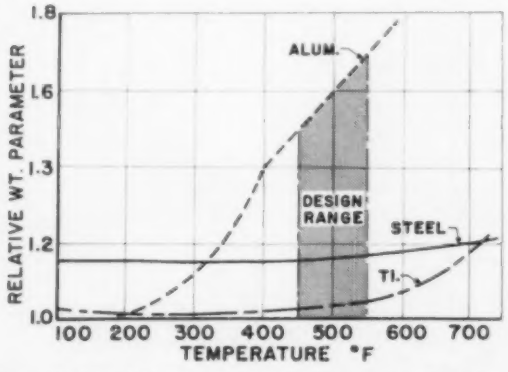


Fig. 7. Relative weight parameter for titanium, steel, and aluminum.

An analysis of the added cost indicates that the 4800 lb weight saving mentioned above would cost approximately $72 per lb additional, or $350,000 more per airplane. These costs are based on low predicted prices of $10 per lb for titanium alloys in 1964. Prices were established by extrapolating current usage and accounting for mill technology improvements. Although the titanium alloys in general are more difficult to fabricate, these costs were based on a scrap rate comparable to that indicated for steel. The most readily fabricated titanium alloy, B120VCA, was used for this comparison.

Producibility considerations

In considering the potential major usage of titanium alloys, the problems of producing a large airframe from them must be carefully analyzed. In our experience, B120VCA can be fabricated by methods now being used for the high-strength steels. However, the material is somewhat more difficult to form; therefore, a higher scrap rate would be indicated.

Other titanium alloys, such as the 6Al-4V, require special techniques such a creep forming. This method would involve a much greater expenditure for tooling. For instance, creep forming requires tools capable of withstanding high forces and high temperatures. It is, therefore, indicated that this titanium alloy is more difficult to form than the steel alloys and would increase the cost of tooling substantially. This factor, coupled with the inexperience which most fabricators have with these materials, adds many intangible high cost factors which were not considered in the above analysis.

High-strength steel alloys will certainly be difficult to form and handle, but substantial fabricating and assembling experience has been gained in this area. Cost penalties are not as severe from higher scrap rates, since the basic cost of steel is substantially lower than titanium, in the order of $1.30 to $3 per lb.

Summary

There are several reasons then for continuing to use the high-strength steel alloys in place of titanium for high-temperature airframe applications:

1) B120VCA titanium is limited to approximately 600°F for long time service, due to apparent severe embrittlement above this temperature; therefore, an airframe of this material would have virtually no stretch.

2) The heat-treatable titanium alloys become less ductile during long exposure at elevated temperature, as indicated by the marked reduction of elongation shown in Fig. 6.

3) In structures which are designed for stiffness, the use of titanium alloys involves a substantial weight penalty; therefore, they are not applicable.

4) Titanium structure is substantially more expensive. The minimum cost above a steel structure is on the order of $72 per lb of weight saved.

5) The corrosion-resistant steel alloys being considered for sheet-metal structure can be fabricated and assembled at less factory effort than comparable titanium alloys; therefore, a steel airplane will be easier to produce on schedule.

Based on this reasoning, it is, therefore, indicated that Mach 3 aircraft will use steel as the basic structural material except in certain specific areas where titanium shows a high competitive advantage.

JET ENGINES, TITANIUM

by G. J. Wile of General Electric Co.

A strong, even enthusiastic, case for titanium in jet engines can be made on the basis of the four fundamental factors vital to the success of any engine program. These are: performance, low cost, high reliability, and growth potential. The following discussion shows how each of these factors is affected in a beneficial way by the use of titanium alloys.

The ability of an engine company to market the lightest weight machine possible strengthens its competitive position on new applications. Consequently, there has been a rapid reduction in component weight—both by design and by the use of better materials. Using specific weight as a measure, Fig. 1 shows how rapidly weight has dropped from the days of the J47 to the present. In the past 11 yr, engine specific weight has dropped from 0.5 to 0.15 (Specific weight is defined as the ratio of engine weight to maximum engine thrust.)

As design engineering ingenuity has matured component designs, the designer has had to increasingly depend on improved materials for more of the required weight reductions. This is particularly true of recent engines designed for very high Mach number flight. In such machines, titanium helps achieve unusually low weight targets. Making the needed weight reductions possible are both the attractive strength: weight ratios of titanium alloys, and their low specific weights. The latter advantage appears so obvious that often its significance is not appreciated. No component design can be so perfectly efficient that there are not large volumes of metal present under relatively low stress. In a compressor disc, for example, the lightly stressed rim volume is an appreciable percentage of the total volume of the part. Here, and in similar situations, the selection of a material using strength: weight comparisons only is not likely to result in minimum component weight. The simple fact is that titanium dead weight is lighter than the highest strength steel dead weight.

Because of metal temperatures over 1000°F in the combustor, turbine, and exhaust nozzle, titanium in jet engines is limited to the compressor end of the engine. Even here titanium cannot be used for all components, because the metal temperatures in the rear compressor stage exceeds 1000°F. Nevertheless, use of titanium for rotor blades, stator vanes, rotor discs and spacers, shafting, and sheet metal components results in vitally needed weight reductions. Table I shows the weight savings possible for a high Mach number machine when components are designed to take advantage of the properties of titanium alloys. In the J57 engine, as much as 443 lb was saved by substituting titanium alloys for steels in the compressor.

It may come as a surprise to some, but in jet engines conditions can exist in which the use of titanium alloys reduces engine cost. Another surprising slant on cost—titanium alloys are among the least expensive materials in use on jet engines. In Table II, for example, the cost of titanium alloy mill products is considerably less than that of many popular super-alloys—even without correcting for density. With the density corrections, even the more expensive titanium sheet alloys are comparable in cost to an extensively-used super-alloy, René 41. Another interesting comparison is with A-286 and V-57, which are austenitic, precipitation-hardened steels frequently considered for compressor wheel applications. With the density correction, the titanium alloys are significantly cheaper than the V-57 alloy, and only slightly more expensive than vacuum-melted A-286.

It is cheaper to handle the titanium alloys than the super-alloys. Billets tend to be cleaner and more homogenous compared to segregation-prone super-alloys. Forging of titanium alloys is easier, requiring fewer reheats. The effect on forging cost is indicated in a relative sense by Table III. Wheel forgings made of titanium alloys can be as much as 50 pct cheaper than similar size forgings made of the more exotic super-alloys. Finally, the machinability of titanium alloys is better than the high-strength super-alloys. Table IV shows how much better titanium broaches —a critical and costly step in the machining of compressor and turbine wheels.

Lower cost for mill product, reduced forging expense, and better machinability, suggests the possibility of reducing over-all engine cost by the extensive use of titanium alloys. This is because ad-

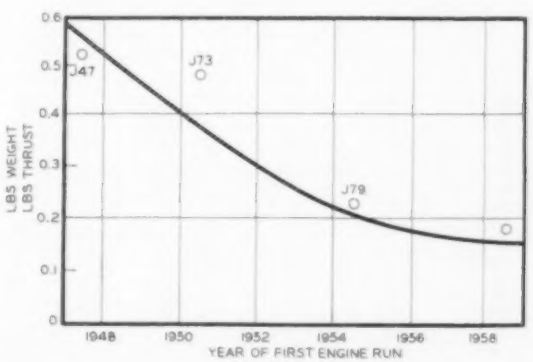


Fig. 1—Reduction in specific weight of jet engines since the J47.

mittedly cheaper, high-strength medium-carbon steels in the compressor can be replaced with the higher-cost titanium alloys. A substantial weight reduction results—as much as 400 lb in some designs. Now the weight of parts using the very expensive, high-strength super-alloys is allowed to increase (offsetting the weight reduction) by substituting weaker, less-expensive alloys. It turns out for some designs this cost reduction more than offsets the premium paid by substituting titanium for the carbon steels.

Outstanding service reliability

Titanium parts in service have had a remarkable record for reliability. Over 1,000,000 flight hours have been accumulated without a single service failure. This experience covers different engine models and different design philosophies. Practically all the usual metal working and metal joining processes are represented in the manufacture of these titanium components. The service experience includes a variety of titanium alloys, such as AllOAT, 6Al-4V-Ti, and Cl30AM. Newer titanium alloys, like 7Al-4Mo-Ti, have performed well under the relatively unknown conditions of experimental engine operation.

Perhaps the single most important reason resulting in the high reliability of titanium hardware is the extensive knowledge gained about the metallurgy of titanium alloys—a tribute to the wisdom of supporting metallurgical research and development programs. A second major factor contributing to reliability is the uniformity of the mill product supplied the manufacturer of jet engine parts by the titanium materials producer. This has decreased the variation in component strength, and has made possible design to higher minimum strength levels.

Of course, much remains to be learned about the metallurgy of titanium and the behavior of titanium parts in service. Design conditions are changing, and service temperatures as well as stresses are heading higher. These newer conditions could reveal new problems. Protection against failure by stress-corrosion, for example, may require development, although our present service experience reveals absolutely no difficulty with this phenomenon.

Table I. Weight Reduction Potential (lb)

Components	Supersonic	Sub-sonic
Frames and cases	45	139
Blades and vanes	90	102
Shaft and spacers	10	32
Discs	75	170
Total weight saved	220	443

Table II. Mill Product Cost (dollars)

	Billet	Bar	Sheet
7Al-4Mo-Ti	3.55/2.00*	4.25/2.40*	—
V-57	4.00	6.50	—
A-286 v.m.	1.80	1.95	2.85
AllOAT		15.50/8.80*	15.50/8.80*
René 41	7.00	8.20	9.00
Astroloy (Experimental)			38.00

* Cost corrected for density

Table III. Relative Forged Disc Costs (dollars)

Cl35AMo (7Al-4Mo-Ti)	1.00
A-286 v.m.	1.00
V-57	1.15
M-252	1.75
René 41	1.95
Astroloy (Experimental	2.40

Table IV. Relative Machinability

	Turning	Milling	Broaching
Titanium alloys	1.00	1.00	1.00
A-286	.75	.60	.40
Waspalloy	.50	.50	.25
René 41	.35	.25	.15

Higher strength at higher temperatures

The market position of an engine improves if the engine has growth potential consisting of better performance, reduced cost, and increased reliability. Since all of these factors are significantly affected by the properties of materials, the engine builder is interested in the growth potential of the materials he uses. If the potential for improved strength is high, the risk of jeopardizing the goals of high reliability and low cost is reduced. The risk is especially great when materials are experimental and used for the first time.

Growth occurs by small improvements won from the same alloy system, thus minimizing the need for new manufacturing processes. Furthermore, the mechanical behavior of the improved alloys can be predicted with high confidence, and the number of unforeseen metallurgical difficulties most likely will be smaller. In recent years, the complex nickel-base precipitation-hardened alloys have been outstanding in their growth potential. The titanium family of alloys also promises to be another outstanding example of alloy growth potential. None of these developments will require unusual or radically different manufacturing procedures, and their mechanical behavior should be fully predictable.

One alloy advance, 7Al-4Mo-Ti, has increased the useful service temperatures about 100°F over 6Al-4V-Ti. Similarly, the newer titanium alloys such as Mallory Sharon's MST 881, Titanium Metals Corp. of America's TMCA 5-5-5, and Crucible Steel Corp.'s 12-7-Ti promise like increases in strength at higher temperatures. Recent work at Armour Research Foundation suggests even greater advances in alloy strength are coming. This work, which has explored the effect of columbium as an alloy addition, may result in 1650°F alloys with acceptable oxidation resistance.

Conclusions

Titanium has proven itself a reliable aero-space age engineering material with its use in jet engines. It offers the opportunity of weight reduction at reasonable cost. In some instances, cost reductions can be achieved by sacrificing some of the weight reduction. In doing this, the use of the more expensive high-temperature super-alloys is reduced. Finally, the elevated-temperature strength of titanium alloys continues to grow. Current experience will remain valid; newer alloys will be used without reducing reliability or excessively increasing cost.

STEEL IN JET ENGINES

by R. E. Patsfall of General Electric Co.

Any comparison of steel and titanium for turbojet application must be tempered by the fact that industry has spent, over the years, more time, effort, and dollars on steel to improve alloys for strength and temperature capability, to increase production, and to improve quality. Consequently, even though both titanium and steel are proven engineering materials, there are certain specific steel applications which have virtually no competitors. For instance, fairly lean ferritic alloys are being used almost exclusively for highly loaded anti-friction bearings. In some of these applications, the soak-back temperatures reached after engine shutdown are as high as 600°F. Certain tool steel grades offer the potential of going to even higher temperatures.

The case for steel is founded on the following factors, all of which help steel retain its dominant position as the most important material behind the rapid advancements made in turbojet engines: 1) improved utilization of high strength by efficient design, 2) excellent strength-temperature capability, 3) low cost, 4) short development time for components, and 5) ease of fabricating light-weight structures.

The term *steel* as used in this comparison refers to the ferritic, metastable austenitic, and high temperature alloys.

Design influenced by temperature

There are several criteria used to measure the performance of a turbojet engine. One of the most important is the thrust for a given engine weight. Significant improvements in the specific weight of an engine can be attained by selecting component materials with a high strength:density ratio at operating temperature. The influence of temperature on both short-time tensile and creep properties of titanium alloy 7Al-4Mo shows that there is a marked drop off in ultimate and yield strength with increasing temperature, and for a design which is limited by 0.2 pct plastic creep in 100 hr, the allowable stress level is dictated by the creep strength of the alloy above 650-700°F. Creep strength is the only time-dependent property used for the comparison of the steel and titanium alloys in this discussion, since resistance to creep is one of the significant factors limiting the application of titanium at higher temperatures.

Variations in compressor inlet temperature, with Mach number at sea level and at an altitude of 36,000 ft, are shown in Fig. 1. Relating this data to temperatures at the front end of the engine, at Mach 0.9 component temperatures range from 0°F at 36,000 ft to 140°F at sea level. At Mach 3.5 the inlet temperature is 870°F at 36,000 ft and as the altitude drops off to sea level, the temperature rises to a formidable 1350°F. Depending upon the performance requirements and the particular flight map for which the engine is designed, compressor discharge temperatures of engines designed for high Mach number flight can range from 900° to 1300°F. These temperatures limit the application of titanium to the front of the engine, and as flight Mach number increases, titanium applications move progressively forward. At present, even low stress titanium applications are limited to 1000°F because of strength and stability considerations.

Steel's high strength better utilized

A high strength:density ratio may not be significant if the designer is unable to utilize efficiently the strength of the material. There are instances in which the selection of a material is merely a matter of providing the mass to satisfy the aerodynamic or functional requirements of the component. Under these circumstances, titanium, a lower density material than steel, provides the lighter weight design. Designers are continually exploring means of increasing the efficiency of the designs, however. Fig. 2 presents a comparison of two design approaches to solving the problem of transmitting high strut loads to the outer structure of a frame. The design incorporating the casting, because of the versatility of configuration afforded by the precision casting of steel strut connections, provides a much better means of fully utilizing the high strength of steel and thereby eliminates *dead* weight from the structure. The welded design is not only hampered by the physical limitations of welding, such as joint accesses, minimum stock thickness requirements, and distortion, but by the complexity of piecing together an efficient sheet metal structure. Since titanium precision castings of the configuration required are not available, the titanium frames must use the completely welded strut connection. As a consequence, the ability to use precision-cast high-strength steel for strut con-

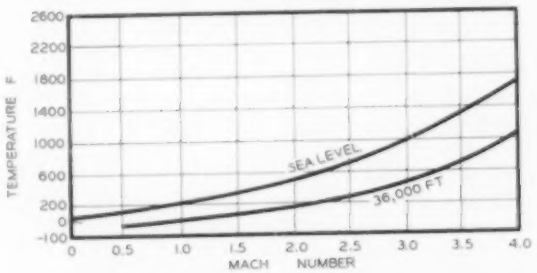


Fig. 1—Compressor inlet temperature vs flight mach number.

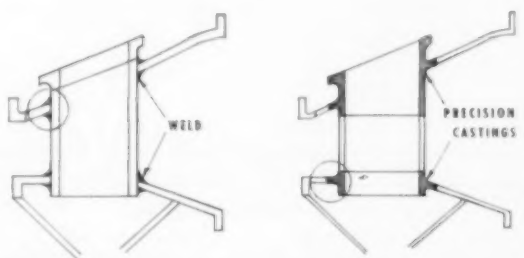


Fig. 2—Two designs for transmitting high strut loads to outer frame structure.

nections and the potential of using the same technique for casting the inner structure to a great extent offsets titanium's inherent low density advantage in the design of light weight frames.

Even more disturbing to the designer are those restrictions placed on his design exclusively because of manufacturing limitations which prevent him from taking full advantage of the temperature and strength capabilities of an alloy. For example, in a design situation in which stock thickness is determined by the minimum sections which can be machined or welded, density becomes the dominant factor in alloy selection. In such cases, titanium would be used in preference to steel, provided, of course, that titanium can withstand the environmental conditions. Advancements in the development and application of new processing techniques, however, are minimizing titanium's advantage because of the manufacturing limitations associated with the processing of high-strength steel components. Metal removal processes such as chem-milling and electrolytic machining have opened the way to machining thinner compressor wheel webs and inner frame flanges. Wide gap brazing, a relatively new method of joining, has supplanted welding for the fabrication of components whose structures are built up of very thin sections. Sheet thicknesses in the order of 0.010 to 0.025 in. can be joined by wide gap brazing in fairly complex structures without the severe distortion and burn-through problems encountered when joining stock thicknesses of this order by fusion welding.

Steel's strength-temperature capability

As mentioned before, comparison of titanium and steel for light weight design in turbojet engines cannot neglect the effect of temperature on the strength-density properties of the alloys. Based on the yield strength curves, only Vascojet 1000 at a hardness of R_c 50 provides strength-density levels above the titanium alloy 7Al-4Mo-Ti. Current design and manufacturing limitations hamper the full utilization of the Vascojet 1000 strength levels, but new design techniques and processing innovations are making application of these types of alloys better competitors for titanium. One of titanium's most serious mechanical property limitations is low creep strength at elevated temperatures. The creep data for forging alloys, compared on the basis of 0.2 pct plastic deformation in 100 hr, indicates a weight advantage for the steels, over 800°F, regardless of type.

For sheet materials, the high-temperature alloys have a weight advantage in yield strength over 700°F and both the low-alloy (Cr-Mo-V) ferritics and the high-temperature alloys have a weight advantage in creep over 750°F.

Cost data comparisons founded on finished component prices are clouded to a great extent by the variation in complexity of the steel and titanium components compared, the number of parts produced, the type of tooling used, and differences in costing manufacturing overhead. Consequently, the cost comparisons shown in Figs. 3 and 4 are based on raw stock prices. These curves also show how a parameter based on the price-per-pound paid for the strength-density capabilities of the materials vary as a function of temperature.

Fig. 3, which is based on billet prices and the relative 0.2 pct yield strength:density ratios of the materials, shows that, except for Inconel X, all the steel materials, including A-286, have a distinct cost advantage from room temperature to 1000°F. The advantage of 7Al-4Mo-Ti over Inconel X is lost at approximately 300°F. The cost advantage of the steels becomes even greater with increases in application temperature. A-286 has an advantage of only 1.3 to 1 at 100°F, but at 900°F the advantage becomes 2 to 1. Fig. 4 shows the same type of comparison as Fig. 3, except for sheet stock. The steel sheet materials, both ferritics and high-temperature alloys, have a marked cost advantage over the AllOAT titanium sheet alloy. Inconel X has an advantage of 3.2 to 1 at 100°F, and 6 to 1 at 900°F. This particular comparison emphasizes the necessity for lower titanium sheet prices. It is not too unusual that the low-alloy steels currently afford more strength-per-dollar to the designer of sheet metal components by a significant margin. However, the fact that the more expensive high-temperature alloys can compete favorably with titanium in its own temperature regime does indicate that the titanium industry needs to effect sizable cost reductions in the production of titanium sheet.

Of course, ease of metal removal is an important factor in the cost of manufacturing components. The relative machinability of the materials was compared by determining the maximum surface speed which can be used to turn a particular material and still maintain a 30 min carbide tool life. Chromoloy and B5F5 are over twice as machinable as titanium, and Vascojet 1000, even at the high hardness level of R_c 50, is nearly equivalent to the machinability of the titanium alloys.

The time cycle required to manufacture hardware for prototype engine testing must of necessity be as short as possible, if we are to make rapid strides in qualifying highly advanced turbojet engines for new weapon systems. The materials used in the engine should be amenable to the methods at hand for manufacturing components, and in addition, should possess a certain tolerance for repair pro-

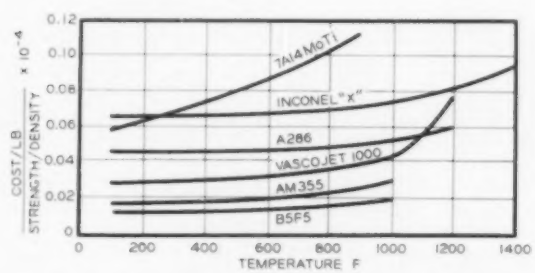


Fig. 3—Yield strength weight cost ratio for billet stock.

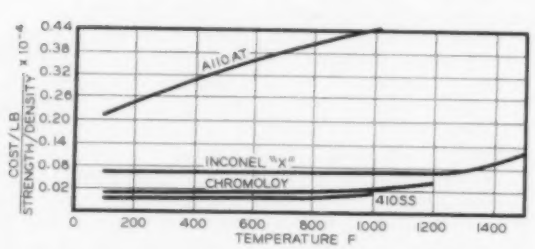


Fig. 4—Yield strength weight cost ratio for sheet stock.

cedures, since changes inevitably have to be made in the engine components because of manufacturing adjustments or design modifications.

The development cycle for the procurement of B5F5 steel and 7Al-4Mo-Ti forged parts was practically the same, with a slight edge going to the steel parts. But the cycle for the procurement of AllOAT titanium sheet metal frames was more than twice that for the procurement of the same type of component fabricated from 410 stainless steel.

There are several reasons behind the longer procurement cycle for the development of titanium sheet metal components. Perhaps the most fundmental reason lies in the exactness with which processing procedures must be determined for such operations as forming, cleaning, welding, and stress relieving. Any deviation from what might be considered optimum conditions is likely to lead to disaster. Other contributing reasons have been the problems of sheet availability and at times the quality of the sheet itself.

Complex titanium weldments are more prone to distortion than similar structures fabricated of steel because of the physical characteristics of titanium. Its high melting point, low thermal conductivity, and high heat capacity lead to wide weld beads and high thermal gradients, which in turn result in high residual stresses and distortion.

The use of halide-bearing cleaning solutions, such as trichlorethylene, has led to serious stress corrosion problems during the fabrication of sheet metal frames. Subassemblies cleaned in trichorethylene cracked during subsequent stress relieving operations because some of the cleaning solution was entrapped in the weldment and carried into the stress relieving furnace. Steel weldments are not fraught with these problems, and in addition, the designer has more latitude in using casting and brazed joints in fabrications, all of which leads to shorter development cycles for prototype sheet metal components.

Steel in light-weight fabrication

Between a titanium compressor rotor blade and a hollow blade fabricated of a high temperature alloy, both blades being designed to the same requirements, the titanium blade was found to be heavier by 20 pct. This extra blade weight pyramids itself into a heavier compressor rotor and, consequently, heavier support frames. The steel alloys are much more easily handled in the fabrication of corrugated and honeycomb structures than the titanium-base materials. In order to take advantage of titanium in light weight fabrications, at a reasonable cost, improved techniques are required for the welding, brazing, and inspecting of these structures.

PRESSURE VESSELS, TITANIUM

by A. Hurlich of Convair-Astronautics, div. General Dynamics Corp.

Pressure vessels discussed in this paper represent the helium gas storage bottles employed in the Air Force's Atlas Missile. A number of these spherical vessels, of approximately 22 and 25 in. diam, form part of the pneumatics system and provide the helium used for the internal pressurization required to maintain the structual integrity of the large, thin-skinned fuel and liquid oxygen tanks of the Atlas. In order to increase the gas storage capacity of these pressure vessels and reduce their size and weight, provision is made to cool the vessels and their contents to liquid nitrogen temperature (-320°F) while the storage bottles are initially pressurized to their operating pressures.

To qualify for the production of these pressure vessels, a manufacturer is obligated to submit three units which are subjected to and must meet the requirements of the following tests: proof pressure test of 4000 psi at both +90°F and −320°F, with no leakage and no permanent set . . . withstand pressures of 5000 psi for 3 min without bursting at both +90°F and −320°F . . . undergo 200 cycles of pressurization to 3000 psi at both +160°F and −320°F . . . and withstand vibration tests over a range of 10 to 500 cps and amptitudes of 0.036 in. or accelerations of ±5 gravities for 45 min while pressurized to 3000 psi and cooled to −320°F. Following successful qualification, all production bottles are subjected to proof pressure testing at 4000 psi at both +90°F and −320°F. In addition, sample bottles are chosen from production lots and are subjected to essentially the same tests used in preproduction qualification.

While the Convair-Astronautics specification for the helium storage bottles does not require them to be made from any specific material, it is obvious that they are restricted to the following selection: titanium alloys, aluminum alloys, steel, or filament-wound resin-bonded plastic laminate.

The 6Al-4V-Ti alloy has been in large-scale commercial production since about 1954. This alloy can be heat treated to tensile strengths in the range of approximately 150,000 to 170,000 psi by a solution quenching and aging heat treatment . . . can be

readily fusion welded with unalloyed low-alloy titanium or matching filler metal . . . is forgeable . . . and possesses good ductility and toughness as evaluated by notched-bar impact tests at subzero temperatures down to at least −320°F. To match the weight of a titanium alloy component at 150,000 psi tensile strength, the same component would have to be fabricated from an aluminum alloy having 94,000 psi tensile strength, an alloy steel of 260,000 psi tensile strength, or a plastic laminate having 56,000 psi tensile strength.

Based upon various limitations of the other materials, the 6Al-4V-Ti alloy was selected by the various vendors who were contacted to provide helium storage bottles for use in the Atlas.

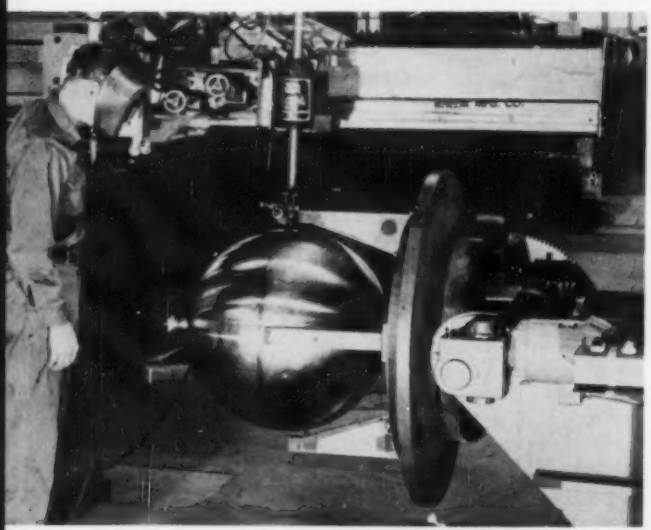
To date, three different facilities have successfully qualified and are producing titanium alloy pressure vessels for the Atlas program. These companies are the Airite Products, Inc., of Los Angeles, Calif.; Menasco Manufacturing Co. of Burbank, Calif.; and the Rheem div. of Aerojet-General Corp., Downey, Calif. All three are employing the 6Al-4V-Ti alloy which is solution quenched and aged to tensile strengths in the range of approximately 150,000 to 170,000 psi.

The basic design and manufacturing methods employed by the three producers are generally similar, but there are a number of noteworthy differences in techniques. All three producers start with forged hemispheres, with each hemisphere having its boss integrally forged, and with walls varying from ⅝ to 1 in. thickness. A close-up of a forging used by Menasco is shown in Fig. 1.

Welding techniques

The major differences in pressure vessel fabrication techniques lie in the welding of the hemispheres to form finished bottles. Airite welds the hemispheres together in specially designed inert atmosphere spherical welding chambers with the welding performed automatically by remote control. The chambers are pumped down, purged with a mixture of helium and argon gases, and welded while maintaining a flow of a 2:1 mixture of argon and helium through the chamber. The filler wire is 6Al-4V-Ti and is fed through a seal in the top compartment of the welding chambers. A ¾-in. wide, 0.060-in. thick back-up strip is tack welded to the inside of one hemisphere, projecting beyond the lip of the bevelled edge. The mating hemisphere is slipped over the projecting back-up strip. After insertion in the welding chamber, the hemispheres are tack-welded around the girth, using a tungsten electrode, with no filler metal added. Then the tungsten electrode is employed to fusion weld the two hemispheres to the back-up strip, after which filler wire is added to complete the weld in two to three passes. The weld joint in the Airite bottle is a single V, complete-penetration weld, using matching filler metal for the weld deposit. The wall thickness of the hemispheres at and adjacent to the weld is increased by about 50 pct and faired smoothly into the thin section.

Rheem welds its pressure vessels in the open air, but employs both welding and trailing inert atmosphere shields to protect the weld during deposition and during cooling from elevated temperatures. The Rheem welding fixture is shown in Fig. 2. The hemispheres are clamped together by means of a tie-rod, and the inside is flushed with inert gas throughout the welding cycle. After the initial fusion pass with a tungsten electrode with no filler metal added, the weld is completed using commercial purity unalloyed filler wire. The weld joint is of single V design, with an overlapping shelf on one of the hemispheres which fits into a recessed groove machined into the mating hemisphere. Because of the weld joint design and the use of unalloyed filler metal, the wall thickness at and adjacent to the weld



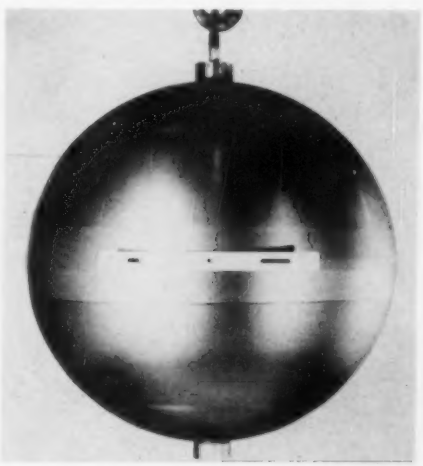


Fig. 1 (left)—As-forged titanium alloy hemisphere forged by Wyman-Gordon Co. for Menasco Mfg. Co. Fig. 2 (above)—Welding fixture used by Rheem div. for girth welding titanium-alloy pressure vessels. Fig. 3 (right)—Completed titanium pressure vessel made by Menasco Mfg. Co.

is increased to about twice the thickness of the wall away from the weld.

Menasco welds the hemispheres together by means of a pressure welding technique which has been given the trade name of *Uniwelding*. The two sections to be welded are carefully fitted together, and under the combined action of heat and pressure are forged butt welded together by upsetting the mating surfaces. Heat is applied by means of a multi-orifice ring burner which oscillates around the mating surfaces to be welded. An hydraulic system applies pressure required to forge weld the two pieces together. By suitable control of the pressure, heating rate, and heating time, it is possible to obtain quite reproducible results in a production run.

The welding pressure is applied to heavy shoulders which are machined on each hemisphere. After welding, the shoulder sections are machined off and the welded zone is faired into the spherical surface of the bottle to yield that finished article shown in Fig. 3.

Following welding, the Airite and Rheem bottles are aged. This treatment also serves to stress-relieve the weld joints. The Menasco bottles must be solution-quenched and aged after welding to produce the desired mechanical properties. After that treatment, the outside surface is chem-milled to remove 0.006 to 0.008 in. of metal which may have become contaminated during heat treatment, since none of the protective coatings presently available is absolutely impervious to oxygen and nitrogen contamination.

The weld deposited metal in the Airite and Rheem bottles are in the as-welded and stress relieved condition. The 6Al-4V-Ti alloy in this condition has a yield strength of approximately 125,000 psi and a tensile strength of approximately 135,000 psi and is both ductile and tough at low temperatures. The unalloyed filler metal in the Rheem bottle has a lower strength than the alloy weld deposit used by Airite. Hence, the Rheem bottle requires a greater thickening of the wall in the weld zone. Tests which have been made through the pressure weld joint developed by Menasco show that 100 pct tensile efficiency is developed in this area, but the wall in the weld area is, nevertheless, thickened by the upsetting of the weld on the inside of the bottles and by the dimensions to which the outside contour is machined after pressure welding.

The 6Al-4V-Ti alloy increases in yield and tensile strengths by approximately 100,000 psi and 90,000 psi, respectively, between room temperature and −320°F, while still retaining good ductility and notched bar impact properties at the extreme subzero temperature. A typical titanium alloy bottle having an ID of 24.2 in. and a wall thickness of 0.246 in. burst at a pressure of 9950 psi at −320°F. This pressure is equivalent to a bursting stress of 240,000 psi; this value represents the full strength potential of the material. When pressure vessels burst at stress levels corresponding to the full strength of the material, a high order of ductility and reliability is indicated. All too often, pressure vessels fabricated from high-strength, relatively brittle materials fracture at nominal stress levels much below the design yield-strengths of the materials. This problem has been particularly troublesome, for example, in solid fueled rocket motor cases fabricated from ultra-high strength steels.

STEEL IN PRESSURE VESSELS

by J. F. Baisch of Boeing Airplane Co.

Steel has been used as a pressure vessel material for many years, and its suitability for this application has been widely demonstrated. The aircraft industry is using many steel pressure bottles ranging from thin-gage stainless steel oxygen tanks to heavier-wall air starter bottles on modern jet airliners. Base installations for a number of missile systems also use steel pressure containers. Engineers working in the field of space vehicle design, however, have developed the need for very light weight propulsion systems and are particularly interested in materials of lower density than steel.

The purpose of this discussion is to compare the merits of steel and titanium for the construction of pressure bottles having the greatest practical strength to weight ratio with a high degree of reliability.

Design requirements

The evaluation of a material for this application must be based on all the requirements specified by the designer. Such factors as shape, service environment, and exterior loads may be equally as critical as the fundamental need for internal pressure containment. Consideration must also be given material fabrication characteristics and the degree of fabrication control required for production.

One method of initially screening alloys is to compare them on the basis of a strength: weight ratio. Fig. 1 illustrates the strength-weight relationship of some of the alloys now in use. The strength used to determine the ratio in this case was limited to a value which has provided adequate notch toughness for specific designs.

The inherent characteristic of a pressure vessel material for resisting crack initiation and propagation is very important. While great care may be

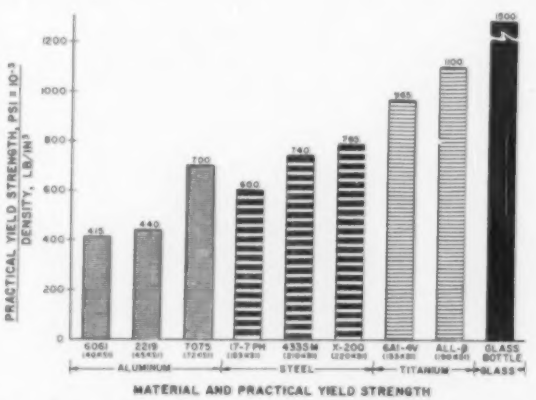


Fig. 1—Strength:weight ratio of some currently used pressure vessel materials.

taken during fabrication, it is impractical to assume that all points of high stress concentration can be reliably eliminated. Both steel and titanium structures may contain sharp notches due to mismatched parts, weld defects, and nonmetallic inclusions. Unusually high secondary stresses may result from contour irregularities such as those associated with welded fittings. The tendency in high-strength steels toward reduced toughness at maximum strength levels is also found in titanium alloys. It is evident, however, from the comparisons shown that, in some designs, titanium has an advantage over steel on a usable strength: weight basis.

The potential weight saving advantage of titanium might indicate, to some observers, a rapid decline in the use of steel for weight critical pressure bottles, but such a reduction is not yet apparent. It is, therefore, appropriate to discuss a few of the factors responsible for the continued confidence in steel.

The service or fabricating environment may limit the consideration of titanium because of reactions which will produce early failure of the material. Fuming nitric acid is used as an oxidizer fuel in some missile propulsion systems. This highly-corrosive liquid is required to be held under pressure for long periods of time without seriously affecting the container material or the acid. The pyrophoric reaction between titanium and fuming nitric acid is now understood and can be controlled; however, the reliability of such a combination is highly questionable and steel continues to serve well in this application.

Residual stresses developed during fabrication combined with very light surface contamination have caused extensive stress corrosion cracking in a roll-formed titanium shell during the aging cycle. While steel alloys are also vulnerable to stress corrosion, our experience indicates they are less influenced by residual stress and, therefore, easier to process.

Fabrication

For any pressure bottle design a material should possess suitable fabricating characteristics. It must withstand the forming process without failure. The quality of available steel and titanium alloys is such that both are capable of meeting this requirement, but tool and processing details are accomplished with less difficulty in steel.

If the bottle components are most efficiently joined by welding, then a welded joint in the material should provide strength and toughness consistent with the base metal. Where fusion welding is employed, titanium alloys are more difficult to handle than steel. The introduction of atmospheric contamination in the weld area must be particularly avoided. A very small degree of such contamination in the cast structure of a titanium weld bead may cause serious embrittlement or the formation of cracks.

In the area of heat treatment the subject metals require strict control. When a high-temperature solution treatment is used, excessive decarburization of steel or surface embrittlement of titanium may occur. The results of several high-strength steel development programs have shown that a slight amount of decarburization actually reduced notch sensitivity; therefore, this factor appears less critical in the case of steel.

Current design trends indicate a preference for the use of heat-treated or cold-worked material joined by welding and followed by a mild thermal treatment for stress relief, or tempering. This permits an optimum combination of weld joint ductility and high-strength base metal with minimum distortion in both titanium and steel.

Conclusions

The rapid advance of titanium technology during the past 10 years has no doubt served to spur the efforts of steel metallurgists toward developing the full potential of ferrous alloys. Refined methods, alloy development, and modified thermal treatments, such as ausforming, are raising the useful strength level of steel products, thus reducing the weight advantage of titanium.

Meanwhile, today's design engineer must decide which alloy most efficiently meets all the service requirements. Past experience with steel gives him confidence in his ability to meet the design deadline with that material. Manufacturing competence and raw material are readily available. Finally, the element of cost remains a significant factor favoring steel. Lower material and processing expense, combined with the greater availability of qualified fabricating sources, give steel a decided edge in a matter of growing importance—defense dollar economy.

SOLID-FUEL MOTOR CASES, TITANIUM

by Jesse Sohn of Curtiss-Wright Corp.

In terms of present production of motor cases, the admission must be made that at least four alloy steels are now being used to produce cases with uniaxial yield strengths in the range of 200,000 psi. No solid-fuel rocket motor cases of titanium are in production. Obviously, a comparison of steel vs titanium cannot be made on the basis of present use, but must be made on the potentials of the materials to meet the needs of the immediate future.

Steel rocket motor cases now being produced are the largest high-strength steel vessels ever made, and their successful production represents

one of the most noteworthy metallurgical accomplishments in the past two years. However, rocket motor designers are demanding strengths considerably in excess of the present 200,000 psi, at 0.2 pct yield strength:. Specifically, they are demanding a yield strength to density ratio of 1,000,000. For steel with a density of 0.283, this means a yield strength in the motor case of 283,000 psi. Even allowing a 15 pct gain in yield due to biaxiality, uniaxial yields in the 250,000 psi range are required. At these strength and hardness levels, notch sensitivity has significantly increased, perfection in geometry is demanded, and a high level of steel cleanliness is mandatory. Heat treating requirements will be most exacting.

Inherent design advantages of titanium

Titanium, specifically the all-beta alloy B12OVCA (11Cr, 13V, 3A1), possesses many inherent properties which go far toward meeting these new design objectives. At a density of 0.175, yield strengths of only 175,000 psi will meet the magic design number of 1,000,000, strength: density ratio. Hardness will be in the low Rockwell C 40's, and this can be achieved with a relatively low temperature heat treatment.

Buckling strength is proportional to the product of the modulus and the cube of the thickness. The lower modulus of titanium is more than compensated for by the increased thickness used for the same weight of titanium vs steel. On an equal weight basis, the titanium will be 25 pct stronger and 100 pct stiffer than steel. The excellent corrosion resistance of titanium needs no comment. The all-beta alloy possesses very good formability at room temperature.

Metallurgical considerations

It is now well known that the as-received solution-treated beta alloy may be hardened by a simple aging treatment in the temperature range of 800° to 900°F. Fig. 1 shows a typical aging curve of 900°F. Strength rises to a maximum after 80 to 90 hr of aging and then decreases. Fig. 2 shows the elongations accompanying the corresponding aging times. At maximum strength, the ductility is low, in the region of 3 to 5 pct. If the aging treatment is followed by holding a short time at 1100°F, ductility may be doubled, with an acceptable loss of yield strength. At 80 hr, the elongation is increased to 10 pct for a yield strength of 175,000 psi. This is shown in Figs. 3 and 4. The action of the duplex treatment, i.e., the short time at 1100°F, appears to be the agglomeration of the hardening precipitate into rosettes.

Returning to Figs. 3 and 4, the solid squares represent the results on welded specimens with the weld in the transverse direction. The gage length was made ⅜ in. in an effort to force the elongation to occur in the weld. Results show an apparent equal amount of elongation and strength in the duplex heat treated welded specimens and in the base metal.

Aging response of the alloy is drastically influenced by prior cold work. The only method by which the original properties could be duplicated after aging was by pre-stressing approximately 10 pct before heat treatment. Increasingly larger amounts of cold work may lower the aging time as much as 90 pct to achieve the same final strength .

In the construction of any rocket case, more than one heat of material and more than one thickness is usually involved. In addition, it has been found that intermediate annealing of sub-assemblies is necessary. This leads to variations in properties which, while not normally excessive, are certainly comparable to the variations noted in the heat treatment of various low-alloy steels used for rocket cases in production.

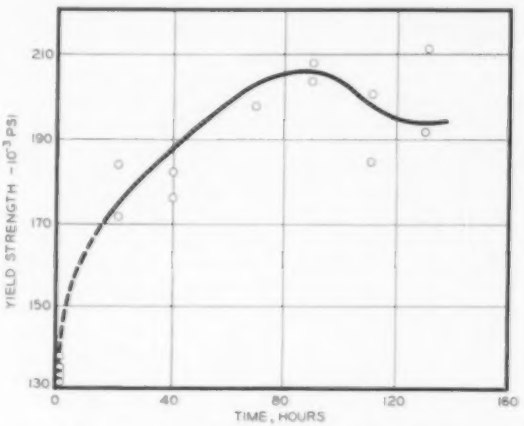


Fig. 1—Aging curve for B120VCA all-beta titanium alloy at 900°F.

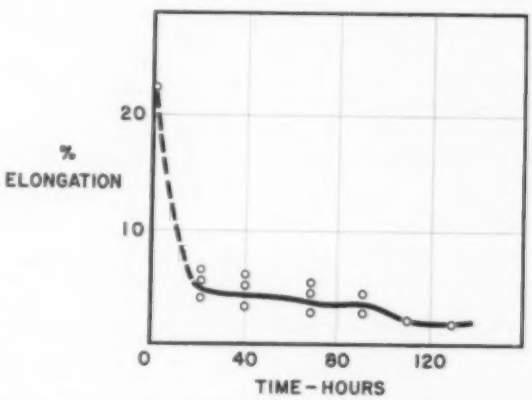


Fig. 2—Elongation accompanying aging time for B120VCA alloy at 900°F.

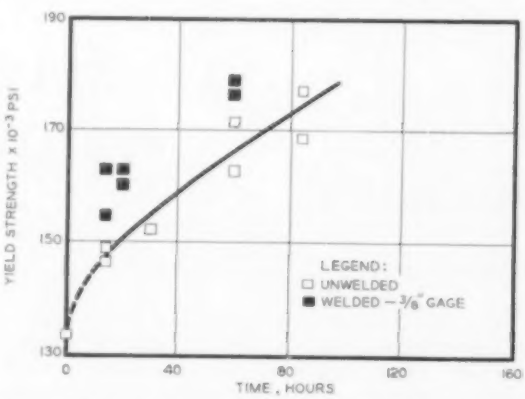


Fig. 3—Aging curve for B120VCA alloy held at 900°F for indicated hours then 10 min at 1100°F.

Fabrication

The problem of variation in heat treat response has already been discussed. This variation is even more serious when considering the effect upon welds. The data shown for the transverse welded specimens (Figs. 3, 4) was deliberately recorded as an *apparent* equal response in strength and ductility with the base metal. When welded specimens are tested with the weld running in the longitudinal direction of the specimen, the ductility drops to or approaches zero. Flush grinding of the weld gives no improvement. In fact, surface micro-cracking occurs. Milling of the weld reinforcement does increase the ductility of as-welded specimens to the neighborhood of 4 to 5 pct. A further drop of this *milled* ductility can be expected after heat treatment. Excessive heat treat response of the weld and its lack of ductility are believed due to the large grain sizes resulting in the weld. These are shown in Fig. 5. For the great majority of materials, an increase in welding speed results in a decrease of weld grain size; however, Fig. 5 shows that increasing speed from 10 to 60 in. per min. has not resulted in any decrease in grain size. In fact, the largest proportion of fine grains are shown at 10 in. per min on the bottom of the weld. The ability to obtain finer grained welds has been reported but has not been duplicated in this laboratory.

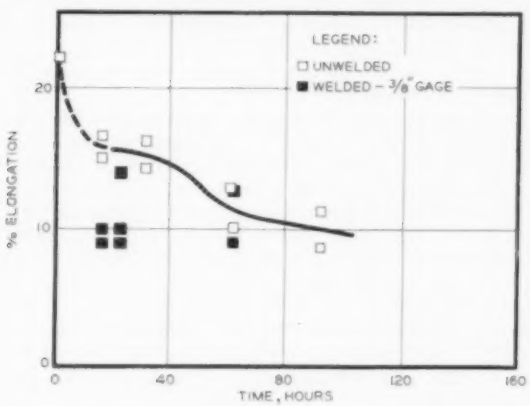


Fig. 4—Elongation accompanying aging time for B120VCA alloy at 900°F followed by 10 min at 1100°F.

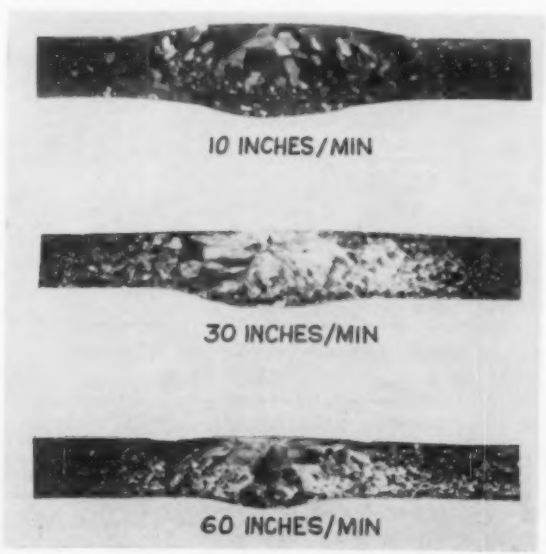


Fig. 5—Titanium B120VCA alloy microstructure at various welding speeds.

The beta alloy is quite sensitive to surface contamination, and this becomes a serious problem when repeated solution anneals are necessary on welded sub-assemblies in the manufacture of a complex rocket case. The contaminated surface may be removed by pickling, but again this is a serious problem in any large-scale fabrication. The necessity for the repeated anneals is due to the presence of strain in the as-welded structures. Heat treatment in the presence of strain results in cracking.

G_c values have been obtained for the base metal and welds[5]. At 148,000 psi yield strength, the base metal has a G_c value of 1100, compared to 214 for the weld. At 164,000 psi yield strength, the base metal has a value of 608 compared to 113 for the weld.

[5] G_c values represent a test to determine energy necessary to initiate and propagate a crack, and are performed on a notched specimen; values are in in. lb per sq in.

It is apparent from the above that the achievement of acceptable strengths and ductilities in welded sheet metal cases is difficult under the present state of technology. This is especially true in regard to longitudinal welds, which are inherently more highly stressed than girth welds. These difficulties are most serious when heat treating the weld is necessary to obtain equivalent base-metal strength. These problems of contamination from repeated solution anneals, excessive response because of strain, and lack of ductility are all avoided when using *beefed* weld joints and limiting the welding to girth welds. Under these conditions, the increased thickness of the beefed joint permits the welds to be used in the as-welded condition. The rings to be welded are heat treated before welding. Sub-scale test vessels, fabricated by shear spinning and using the fabrication method outlined above, have burst at strengths over 200,000 psi. Several vessels have burst at strengths over 235,000 psi.[4]

Conclusions

It is evident that much remains to be done to achieve a full understanding of and solutions for the problems still existing in the use of the all-beta titanium alloy. However, the inherent advantages of low density . . . low-temperature heat treatment . . . corrosion resistance . . . low as-welded hardness . . . and good formability fully justify the intensive effort being expended on this alloy. The potential for a significant materials breakthrough for solid-fuel rocket motor cases is higher than for the steel alloys, which are already near the upper limits of their useful strength.

The immediate future use of this alloy should obviously be limited to fabrication methods which use only girth welds on joints thicker than the base metal so that they may be left in the as-welded condition. With this restriction, motor cases can now be made which appreciably exceed the strength to density ratios achievable with the present steel alloys.

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STEEL IN SOLID FUEL MOTOR CASES

by D. K. Hanink

of Allison div., General Motors Corp.

Engineering criteria for material selection, processing, and quality control, when applied to solid-propellant rocket motor cases, represent a continuing effort. But when it became increasingly apparent that better fuels might be limited by the strength of solid-fuel containers, design and metallurgical engineers were prompted to examine, with renewed interest, all materials which might exhibt appropriate strength: weight ratios.

Studies in connection with aircraft landing gear applications provided a wealth of information on performance of high-strength steels, some of which comprise compositions now in various degrees of usage on investigation for rocket motor case applications. These include X-200, H-11, 300 M, D 6, SAE 4340, and AMS 6434.

Titanium-base alloys were omitted from this consideration because the sense of urgency in developing large motor cases called for quality and availability of material, processing and inspection procedures with extensive production experience, and minimum-cost material to meet these qualifications.

Fig. 1—Relationship between the Allison IB test and the NRL test in resistance to crack propagation of H-11 steel, tempered in different uniaxial tensile strength levels.

Beyond this, attention must be given to design criteria, such as the section modulus of the entire structure, i. e., the effects of external loads producing bending and torsion which might reflect a net reduction of the strength:weight advantages of certain low-modulus materials. Furthermore, it can be shown that deflection from external forces and/or radial growth in proof pressure testing are on the same order of magnitude. It then becomes clear that the growth potential of steel for solid-propellant rocket motor case applications may be limited, not for strict metallurgical consideration, but through limitations imposed by design requirements.

However, these same design requirements have dictated an intense study of certain critical mechanical properties of the special high-strength grades of steel which have already been successfully applied in motor cases. Some of the pertinent mechanical properties of these steels are shown in Table I.

Uniaxial strength levels were specified at approximately 200,000 psi at 0.2 pct yield strength. All of the steels listed can be heat treated to strength levels which consistently meet uniaxial tensile strengths of 270,000 to 300,000 psi. However, consideration must also be placed on the ability of the material to resist crack initiation at discontinuity locations and the further propagation of the crack once initiated.

Crack propagation tests

A number of tests have been proposed which are designed to provide some relationship between crack initiation and propagation resistance with behavior under high-stress conditions.[1] Among these are the Irwin center crack tensile test,[2] the Srawley modification of this, and others which employ external notches in tension or bending. Information on the Irwin test, made available through publication of non-classified work at the Naval Research Laboratory, indicates that the G_c* value obtained may

* G_c values represent a test to determine energy necessary to initiate and propagate a crack, and are performed on a notched specimen; values are in in. lb per sq in.

Table I. Mechanical Properties of Selected High-Strength Steels

Designation	Recommended Hardening Treatment: Austenitize	Recommended Hardening Treatment: Cooling Medium	Tempering Treatment, °F	R_c Hardness	Tensile 0.2 Pct Yield, Psi
X-200	1725°F	Air Cool	900	50	200,000
H-11	Preheat 1450°F Austenitize 1800-1900°F	Air Cool	(Double) 1060	50	215,000
300 M	1600°F	Air Cool	1000	46	200,000
D6[a]	1550°F	Air Cool	1050	47	210,000
SAE 4340[b]	1525°F	Marquench	800	46	200,000
AMS 6434	1650°F	Marquench	725	46	205,000

[a] Allison EMS 65030.
[b] AMS 6415.

Table II. Irwin Center Crack Tensile Test Results on High-Strength Steels

Type	Form	Direction of Load Application	Uniaxial Tensile 0.2 Pct Yield, Psi	G_c in Lb,* Rm Temp
X-200	Sheet(.07 in.)	Longitudinal	194,000	800[4]
H-11	Sheet(.09 in.)	Longitudinal	250,000	50
		Longitudinal	205,000	1200
300 M	Sheet(.09 in.)	Longitudinal	190,000	550
D 6	Sheet(.06 in.)	Longitudinal	205,000	>3000[3]
AMS 6434	Sheet(.06 in.)	Longitudinal	207,000	975[3]
		Transverse	211,000	275

form a suitable index for categorizing materials. Some of these are shown in Table II.

Examination of this data revealed an expected scatter of results which may reflect laboratory procedure or variation between heats. However, conclusions can be reached that: 1) crack propagation tests differentiate between steels of similar composition and tensile properties; 2) the sensitivity of the test allows accurate evaluation of the isotropy of the material; 3) such testing may provide suitable developmental quality control and govern usable strength levels under biaxial stressing; and 4) the effect of processing variables involved in fabrication procedures can be evaluated.

The importance attached to the ability of these grades of steel to provide full reliability against premature fracture prompted a development program on crack propagation testing. The result of the program is the Allison-developed Instrumented Bend Test (IBT), which provides a bend biaxial stress parameter correlating with pressure vessel behavior.[6] The test specimen is 1.5x0.052x0.700 in. and is subjected to biaxial stressing to failure. As bending occurs, load and deflection are recorded on the strip chart of a Sanborn recorder, which amplifies the signal from a strain gage load cell.

On typical tracings representing material tested in both a brittle and a ductile biaxial behavior, the maximum load has been identified as the point of crack initiation, while the second significant point represents the final fracture. Thus, crack propagation resistance of the material should be related to the difference between these loads; this has shown close correlation with pressure vessel behavior.

The test is a suitable quality control procedure, and its further use as a metallurgical capability requirement has been established. For example, comparing H-11 steel in this test with the Irwin center crack test in Fig. 1 for different tempering temperatures and corresponding yield strengths, the curves provide a striking similarity. The data emphasize the critical nature of the tempering temperature and imply that, with experience, one can select a minimum acceptable value for the best product reliability.

Most of the steels discussed in this paper reflect the general configuration illustrated for H-11 steel in Fig. 1. They differ only in degree of severe reduction of crack propagation resistance at the lower tempering temperatures, i.e., 800° to 1000°F.

Conclusions

In this class of steels, where their full biaxial capability is being utilized, metallurgical tools are now available to narrow the selection. Current production needs in highly efficient solid-propellant systems can be met by materials which yield lowest cost manufacture in fully acceptable strength: weight ratios, while maintaining a maximum of reliability based on experience gained in its usage.

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APPLICATIONS CHEMICAL AND MARINE, TITANIUM

by G. R. Prescott of C. F. Braun & Co.

The corrosion resistance of titanium could solve many problems that have plagued the chemical industry for years. In spite of this, the increased availability of titanium has not resulted in a stampede for titanium process equipment. Although applications have increased, only a small portion of the potential market has been developed. The purpose of this presentation is to outline the advantages of titanium and to discuss reasons why titanium should be more fully utilized by the chemical industry.

Titanium exhibits good resistance to a number of corrosive media. In nitric acid, for example, titanum is resistant to all concentration up to the boiling point, and exhibits good resistance at temperatures above the boiling point. Beck and Fontana[1] made comparative tests on titanium and stainless steel at elevated temperatures in 65-pct nitric acid. The superiority of titanium is illustrated in Fig. 1.

Laboratory data of this type has been substantiated by actual service experience. An example reported in the literature[2] describes an application of Type 304 exchanger tubes in 65-pct nitric acid at 325°F. After five months, the exchanger tubes were replaced with titanium. The corrosion rate of Type 304 tubes was measured at 0.118 in. per year as compared to 0.002 in. per year for titanium.

Titanium exhibits excellent resistance to inorganic salts. Of special interest is its resistance to chloride salts, as shown in Table I.[3,4] With the exception of aluminum chloride and zinc chloride, titanium is

resistant over a wide range of concentrations and temperatures. This remarkable resistance to chloride salts is associated with titanium's complex mechanism of passivation. Passivity is attributed to a thin, adherent film that is formed and stabilized in the presence of oxidizing agents or one of several metal ions.[6]

Titanium is not effectively resistant to reducing mineral acids, such as hydroflouric, hydrochloric, or sulfuric. However, the addition of small amounts of an oxidizing agent or metal ion will inhibit corrosion in hydrochloric and sulfuric acids. Table II shows the effect of adding small amounts of cupric sulfate or nitric acid to hydrochloric and sulfuric acids.[6] Ferric ion, like cupric ion, will inhibit corrosion in these acids.[7] The addition of ferric ion to reducing acids promotes aggressive pitting and corrosion of austenitic alloys.

Others[8] have noted that titanium can be passivated in corrosive solutions by mere contact with more noble metals. Stern[9] carried this a step further and added small amounts of palladium or platinum to titanium as alloying elements. The effect of these additions on the corrosion rate of titanium in boiling hydrochloric acid and in boiling sulfuric acid is such that as little as 0.05 pct Pd or Pt reduces the corrosion rate by a factor of 100 or more. The addition of a small amount of palladium does not alter titanium's resistance to oxidizing environments.

Titanium is considerably more resistant to pitting and stress-corrosion cracking than materials in the stainless steel class. Tests have been made in most of the solutions that are normally associated with this type of corrosion.[10,11] None of the solutions induced pitting or cracking in titanium. Only red-fuming nitric acid, molten cadmium, and a chlorinated hydrocarbon under severe conditions, have produced cracking problems in titanium.[12,13] In addition, titanium welds and weld heat-affected zones appear to be equally as corrosion-resistant as the parent metal. This advantage is a result of the simple structure of commercially-pure titanium. The more complex austenitic alloys are subject to accelerated corrosion resulting from phase changes induced by the welding operation.

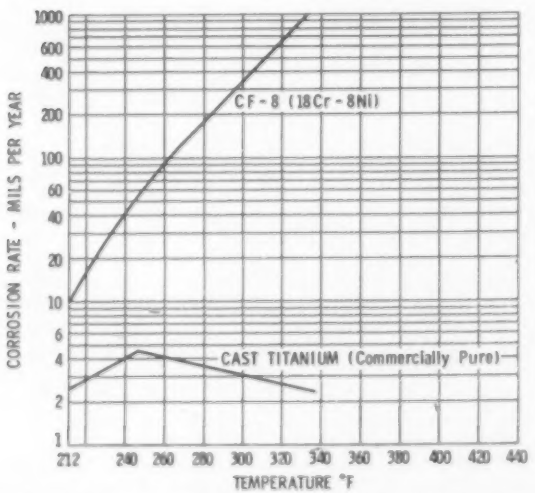

Fig. 1—Corrosion rates vs temperature in 86 pct HNO_3 (from Beck and Fontana).

Applications

Many applications of titanium have been described in the literature. In general, these applications involve a corrosive media under highly erosive conditions. One example is a titanium let-down valve taking a 2700 psi pressure drop in a corrosive service. A stainless valve lasted about 70 hr in this service, compared to about 70 days for titanium.

The striking inference from these applications is that titanium can withstand the action of corrosive liquids under conditions of high-velocity and turbulence. Heat exchanger design based on high velocities result in higher overall heat transfer rates and reduced surface-area requirements. In seawater, for example, comparative tests made with a rotating disk at peripheral speeds of 27 fps showed that titanium is considerably more resistant than the more commonly used materials, see Table III.[14] In addition, titanium proved to be highly resistant to cavitation attack.

The chemical industry's interest in titanium is reflected in a recent publication by Gegner and Wilson.[15] The authors reported the results of a series of plant-exposure tests that compared titanium and zirconium with other corrosion-resistant materials. A vast amount of valuable data reference is contained in the report. Some of the data are summarized in Table IV, showing titanium's resistance to chloride salts, wet chlorine gas, and nitric acid. In addition, Gegner and Wilson confirmed laboratory results in

Table I. Corrosion Test Results in Chloride Solutions (10-Day Tests)

Solution	Conc., Pct	Corrosion Rate, Mils Per Year		
		Boiling	150°C	200°C
$AlCl_3$	10	1.1	1.3	
	40	4300		
$CaCl_2$	70	Nil	Nil	
	80			0.2
$CuCl_2$	55	0.1		
$FeCl_3$	50	0.7	0.1	
$HgCl_2$	55	Nil		
KCL	29	0.1		
$SnCl_4$	20	0.3		
$ZnCl_2$	20	Nil	0.2	
	75	2.4	Nil	24
	75-90	1200		
	80	81		3000
$MgCl_2$	42		Nil	
	50			0.2

Table II. Effect of Inhibitors on Hydrochloric and Sulfuric Acids

Acid	Acid Conc., Pct	Temp, °F	Corrosion Rate, In. Per Year
HCl	10	35	0.0420
HCl + 0.05-pct $CuSO_4$	10	66	0.0013
HCl + 0.10-pct $CuSO_4$	10	66	0.0006
HCl + 0.20-pct $CuSO_4$	10	66	Nil
HCl + 0.70-pct HNO_3	10	66	0.0013
H_2SO_4	65	70	0.072
H_2SO_4 + 0.70-pct HNO_3	65	70	0.001

Table III. Results of Tests Made at a Velocity of 27 fps (60-Day Test)

Material	Wt Loss, Mg Per Sq In.	Resistance Relative to Titanium, Pct
Titanium	0.14	100.0
70 Ni-30 Cu	61.4	0.23
70 Cu-30 Ni-½ Fe	198.0	0.07
18 Cr-8 Ni	12.4*	1.13

* Severely pitted.

media such as hypochlorous acid, hypochlorites, and sulfuric acid concentrations up to 72-pct in the presence of chlorine acting as an inhibitor. The results of the corrosion-testing program have stimulated the use of titanium in plant equipment.

A recently completed nickel-cobalt extraction plant, owned and operated by Freeport Nickel Co., represents the biggest single application of titanium in the process industries. The leaching plant at Moa Bay, Cuba, used approximately 37,000 lb of titanium in the form of heat exchangers, process piping, valves, and reactor internals. The purification plant at Port Nickel, La., required an additional 8,000 lb in process equipment. Simons[16] described the process and presented a summary of the design problems and material problems associated with the plant. The focal point of the process is the leaching plant. Briefly, the leaching process consists of contacting a thickened ore slurry with 98-pct sulfuric acid. Leaching takes place between 400° to 500°F at a pressure in excess of 500 psi. The acid is rapidly consumed and the residual acid content seldom exceeds 3-pct.

The resulting corrosive-erosive system consists of an aqueous suspension of fine iron ore, about 36-pct solids by wt, and a solution phase containing nickel, cobalt, and other metallic ions. The metallic ions apparently act as an inhibitor and reduce the corrosion rate of titanium to an acceptable value. In 1-pct sulfuric acid alone, titanium would be rapidly consumed under the operating conditions. According to Simons,[16] nickel alloys, stainless steels, and nickel-chromium molybdenum alloys are not resistant to this service.

Fabrication

The large-scale use of titanium piping and process equipment in the nickel-cobalt plant represents a major advance in titanium fabrication. Plate as thick as 3/8-in. had to be rolled and welded into 8-in. diam pipe. Following this, the pipe was fabricated into finished pipespools by bending the pipe into various configurations, adding cast stub ends for flanged connections, and numerous branch connections. Fig. 2 shows some of the complex design details of the pipespools. In addition, eight large heat exchangers with titanium tubes and titanium-lined channels and floating heads were carefully designed and fabricated. Process equipment of this size presented new problems to the fabricators, and the success of the assignment required the cooperation of many individuals and companies.* The fabrication experience gained from equipment of this size warrants a brief review.

Forming of plate into pipe, and pipe into pipespools was accomplished without difficulty. All forming operations were done with the temperature maintained between 600° and 1000°F. Centrifugally cast fittings, in the form of lap-joint stub-ends and reducers, were of exceptionally high quality. And 16 5-in. valve bodies were statically cast to ASTM E71, Class II specification.

Titanium was fabricated by conventional methods, with due consideration for its properties. Hand grinding, for example, can be used for removing small amounts of metal, provided the operator does not overheat the metal by dwelling in one spot. Oxyactylene cutting was also used to advantage under controlled conditions and subsequent removal of the torch-cut edge by grinding.[17, 18]

An important accomplishment was the successful and widespread use of open-air welding on a production basis. On the piping alone, over 600 welds

* C. F. Braun & Co. engineered and designed the leaching plant at Moa Bay, Cuba, and the purification plant at Port Nickel, La. The heat exchangers were fabricated by Struthers Wells Corp. Welded pipe and reactor internals were fabricated by The Nooter Corp., and Crane Co. fabricated the finished pipespools. The cast fittings and valves were supplied by the Oregon Metallurgical Corp.

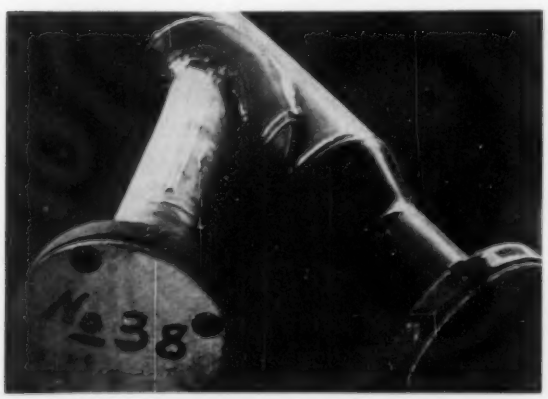

Fig. 2—Fabricated titanium pipe for Freeport Nickel plant.

Table IV. Corrosion Tests for Titanium and Other Metals

A. In Wet Calcium Chloride Solutions

Media	Temp, °F	Duration of Test, Days	Corrosion Rate, Mils Per Year			
			Ti	Ni	Monel	Inconel
55-pct $CaCl_2$ plus NaCl and $CaSO_4$	220	174	Nil	8	9	8
55-pct $CaCl_2$ plus NaCl and $CaSO_4$	235	120	Nil	23	12	7[a]

B. In Wet Chlorine Gas

			Ti	Hastelloy C	Chlorimet 3
Wet Chlorine Gas, containing salt brine spray	190	28	Nil	210	149
Wet Chlorine Gas, containing salt brine spray	205	40	Nil	222	271

C. In Nitric Acid

			Ti	304	304L	310
45-65 pct HNO_3, containing 5 ppm Cl and 11-13-pct zirconyl nitrate	260	10	Nil	63	120	18
65-pct HNO_3, containing small amount of zirconyl nitrate	265	36	Nil	57		450[b]

[a] Moderate attack under spacer.
[b] Welded specimen.
Source: Gegner and Wilson[15]

Table V. Allowable Design Stresses for Titanium and Steel, ASME Code

Material	Design Stress, psi					
	−20° to 100 °F	200 °F	300 °F	400 °F	500 °F	600 °F
A-240—Type 316	18,750	18,750	17,900	17,500	17,200	17,100
B-265—Grade 3	14,000	11,400	9,600	8,250	7,150	6,400

were required to complete the assemblies. With a few exceptions, both autowelds and handwelds were made using a trailing shield on the torch and simple fixtures to provide an inert atmosphere on the opposite side of the welds. The few exceptions involved joints of complicated geometry that required the use of an inert-gas chamber. Chamber welding is inherently more expensive than open-air welding, and a considerable savings was realized by the use of the simpler welding process. The use of open-air welding did not lower the quality of the weldments.

Cost

The cost of equipment can be broken down into two parts: 1) cost of mill products, and 2) cost of fabrication. In 1957 titanium sheet cost about 15 times more than Type 316.[19] Today the price ratio is slightly more than nine. If the downward trend continues as predicted by H. H. Kellogg,[20] the eventual cost of titanium will be $2.10 to $3.50 per lb for mill products. At this level, titanium will be competitive with nickel alloys and stainless steels. And with more experience in fabricating titanium, the fabrication costs should be correspondingly lower.

The comparison of costs on a volume basis favors titanium, and it is a valid comparison where a volume for volume substitution is possible. However, where elevated temperature and pressure are design considerations, titanium may rapidly lose its advantage because of low design stresses. As shown in Table V, the allowable design stress of titanium is lower than Type 316 stainless steel at room temperature. The difference becomes more pronounced with increasing temperature. A pressure vessel constructed of titanium would require a thicker shell, or greater volume of metal, than the same vessel made of Type 316 stainless. For example, compare the weight of titanium and Type 316 stainless required in a 60-in. diam shell designed for operation at 200 psig and various temperatures. As shown in Fig. 4, more pounds of titanium are required than Type 316 above 245°F. Even this disadvantage may be short-lived, considering the recent success reported in producing titanium-clad steel.[21] Special welding techniques were used to fabricate the clad material into a 4-ft diam pressure vessel designed to operate at 150 psi at 500°F.[22]

Future use

An evaluation of the pros and cons of titanium in the process industry indicates that titanium applications will increase rapidly in the next few years. Titanium is a relatively new metal to the industry, and experience will be accrued from small-scale applications. The successful performance of these applications will eventually lead to uses on a larger scale. At present day prices, titanium is directly competitive with the highly-alloyed materials commonly used in extremely corrosive media. If the downward trend in the cost of titanium continues as expected, each decrease in price will increase the number of applications that can be economically justified.

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METALS IN CHEMICAL AND MARINE APPLICATIONS

by Frederick W. Fink

of Battelle Memorial Institute

In choosing a metal for corrosion resisting service, one must consider availability, physical properties, cost, formability, and so on, as well as environmental factors.

Corrosion problems are not always solved by the use of a more resistant metal. It is often possible to improve the design to reduce or avoid corrosion of a less-resistant metal. The corrosion may be eliminated by cathodic protection. Sometimes, one can change the chemical process or environmental conditions sufficiently to allow the use of a less-expensive material.

But once it is established that the best solution to the problem is the use of a corrosion-resistant material, one has to admit that titanium offers very strong competition to a variety of older, well-established corrosion-resistant metals. However, for today's material costs titanium is not necessarily the most economical choice. In addition to the price of the material, one has to consider other economics associated with the costs, such as the expected life of the plant or process, and the availability of titanium vs other materials in the particular form needed for the application at hand. For pressure vessels, for example, titanium-clad steel is becoming available. However, there are still problems in the construction and repair of such vessels. Only a limited amount of service experience is available.

Let us consider costs, for example. Among the available materials that are considered for chemical

service and, in some cases, for marine applications is Hastelloy C. In sheet form it costs about $3 per lb, which works out to about $1 per cu in. Titanium sheet is of the order of $8 per lb or $1.30 per cu in. It can be seen that Hastelloy C and titanium, on a sheet-thickness basis, are becoming competitive. Of course, there may be extras for each material for a given application.

Tantalum varies widely in price—starting at $50 to $60 per lb in sheet form. Zirconium, which we can assume costs roughly $15 per lb in sheet form, is about $3.50 per cu in. Type 316 stainless steel, which is considered the *work horse* metal in the chemical industry, costs about 65¢ per lb per cu in. It is clear that, for the price of titanium, one could provide five or six times as much wall thickness in a vessel of Type-316 stainless steel. For a chemical plant, there are many applications in which Type 316 stainless steel is sufficiently resistant.

It should be emphasized that the cost of steel is very much less than any of the special alloys or exotic metals. In a plant that is to be in use for only a few years, the cost of expendable steel may be far less than alloy construction. Steel is readily available in almost any form. By using very heavy walls or employing some form of protection—such as cathodic protection, a lining of rubber, plastic, or glass . . . a chemically-resistant paint coating . . . or even a layer of brick, cement, or wood planks—the use of an expensive material, such as titanium, can sometimes be avoided.

Mineral acids and sea water

For many of the mineral acids, titanium is unsuitable at most concentrations. However, a small addition of palladium to the titanium alloy shows promise in extending the range of its usefulness in mineral acids. It is well known that the addition of cupric or ferric ions may also extend the range of titanium with some of the mineral acids. But neither of these techniques alters the basic fact that titanium is generally unsuitable in sulfuric, hydrofluoric, and hydrochloric acids.

For sulfuric acid, the Illium-type alloys, Hastelloy C, Carpenter 20, Nionel, and Type 316 stainless steel, have given outstanding service, provided they were used in the most suitable of acid concentrations and temperatures. Tantalum, a high-cost metal, performs very well in sulfuric acid; zirconium is almost as serviceable and has the advantage of being less expensive.

For hydrochloric acid service, titanium and its alloys are wholy unsuitable, except in rather dilute concentrations and mild conditions. Zirconium performs well in hydrochloric acid. Hastelloy C is also useful in a more restricted range of conditions.

For hydrofluoric acid service at high concentration, steel is used. For a wide range of concentration, silver, Monel, and cupro nickel give good performance.

In oxidizing media, e.g., nitric acid, titanium often performs well and compares with the austenitic stainless steels.

Only in carefully-controlled flowing sea water, will stainless steel be found resistant. Depending on the application, Monel cupro nickels, and certain bronzes and brasses give excellent service in sea water. Sea water, however, is an example in which the environment can sometimes be changed. It has been demonstrated, at Wrightsville Beach, N. C., that by first deaerating, one can handle hot sea water in plain carbon steel.

Applications considered

In some service applications, such as the food and pharmaceutical industries, the solution may not be the same as for problems involving over-all corrosion resistance. Even where the material is resistant, a slight amount of attack may still contaminate the product.

In a heat exchanger a variety of properties are required of the metal. The designer must weigh the relative advantages of the metals that have good corrosion resistance. The thermoconductivity of the material itself does not permit one to choose between the relative serviceability of titanium vs a copper-base alloy. On the basis of thermoconductivity data, a titanium heat exchanger handling water would have 18 times the surface area of one built of copper. However, there is considerable heat loss across the thin film barrier adjacent to the metal. If one considers the film coefficients of a heat exchanger with steam on one side and sea water on the other, the ratio for a clean copper-tube heat exchanger compared with one made of clean titanium might only be 2:1 or 3:1 at the start of the operation. If there is corrosion, fouling, or mineral-scale formation on the sea water side, this may result in a large loss in heat transfer capacity.

With titanium, it is possible to increase sea water velocity considerably above that of many other metals, e.g. to 20 ft per sec. Such velocities, and the use of thin walls, overcome the lack of good thermoconductivity. This may also help retard formation of deposits. Copper at high velocities would suffer rapid impingement attack. At intermediate velocities, a series of cupro-nickel alloys have been developed to provide excellent life in sea water.

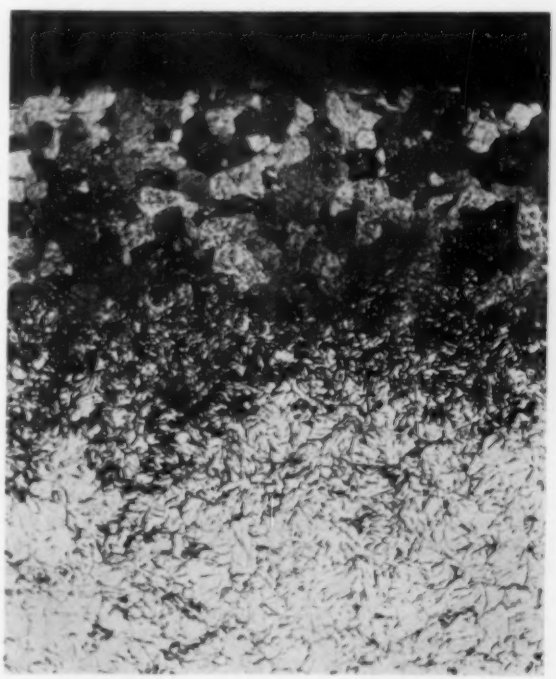

Fig. 1—Pictomicrograph of unalloyed titanium after exposure to a chemical environment containing a trace of hydrogen. Top shows exposed surface, with hydride layer below this, and hydride needles in alpha titanium matrix at bottom of picture. X100.

It should be pointed out that in special situations duplex tubes are available. For example, duplex tubes can be made by various processes which provide corrosion resistance to different conditions, such as titanium or Hastelloy C on the sea water side and a copper alloy on the fresh water side.

Special properties of Ti

There are a number of properties of titanium which need further study before titanium can be completely accepted as a corrosion-resistant material.

Hydrogen pickup: One property which can be troublesome is hydrogen pickup by the metal surface. Titanium has a high affinity for hydrogen and may absorb a portion of any hydrogen liberated during a corrosion reaction, even at room temperature. In some instances, this may lead to the complete embrittlement of the surface by the formation of a hydride layer. In some cases, hydrogen tends to enter at relatively hot areas and migrate to colder sections of the metal. An example of hydride formation on titanium is shown in Fig. 1.

Titanium construction was used in a chemical process where a small amount of hydrogen was present in the process stream as an unintentional impurity. In areas where the flow rates were rather high, the protective passive film, which naturally forms on titanium, was eroded away. This left a fresh surface, which reacted rapidly with the trace of hydrogen in the system. A hydride layer formed; it cracked and spalled off, exposing a fresh surface to more hydrogen. The net result was a severe loss of the metal surface.

Passivity: In another example, titanium was evaluated for a service condition using a boiling mixture of nitric and hydrochloric acids. During the operation of the experiment, the nitric acid content of the mixture became depleted. At a given concentration, the titanium in the vapor phase suddenly started to disintegrate. Chemical tests showed there was no oxidizing nitric acid left to maintain passivity. Such a process would have to be carefully monitored to avoid this type of an incident. While this is an uncommon situation, it illustrates the importance of providing an oxidizing agent or addition to promote passivity in the acid solution.

Pyrophoric: Titanium has been found to be pyrophoric in several environments. One of these is anhydrous red, fuming nitric acid. There are indications that the corrosion product formed is very finely divided titanium. This powder is extremely sensitive to shock in the presence of red, fuming nitric acid. Explosions have resulted because of the pyrophoric reaction of titanium with this acid. Even when detonation does not occur, serious attack may occur locally and, in some cases, there may be deep penetration of the metal at localized areas. It has been found that adding water above 1.5 pct to the anhydrous acid allows one to use titanium safely.

Stainless steels are widely used in nitric acid solutions and are resistant to anhydrous red fuming nitric acid.

Titanium is subject to violent reactions under some conditions involving the presence of oxygen under pressure. One case involves a titanium poppet valve which suddenly failed at Oak Ridge National Laboratories while in service in oxygenated uranyl sulfate solution. Galling or abrasion which were under oxygen pressure seems to favor the reaction.

In another case, titanium was tested in various oxygen atmospheres. Of the other materials evaluated, zirconium, magnesium, aluminum, iron, stainless steel, tantalum, columbium, and molybdenum, only zirconium showed pyrophoric behavior similar to titanium.

There are some reports that titanium is impact sensitive to liquid oxygen. Here, however, a fresh surface does not appear to be the controlling factor. The presence of a pressure bubble of gaseous oxygen may be important. It is possible that extremely high velocities of flow may set off a reaction. A number of laboratories are investigating this problem at the present time.

Stress corrosion: Titanium and its alloys, although very resistant to stress corrosion cracking in aqueous chloride solutions, have been found to be susceptible to a type of stress corrosion at temperatures above 500°F, in high stress, and in contact with dry crystalline sodium chloride. It should be emphasized that the attack occurs well below the melting point of sodium chloride. Even a small amount of sodium chloride residual found in a fingerprint may result in such cracking. In a study of the hot-salt cracking of titanium alloys, it was found that the cracks tend to follow the alpha-beta interface in two-phase alloys and the grain boundaries in single-phase alpha alloys. Stainless steels and nickel-base alloys are not susceptible to this particular type of cracking in the 500°to 800°F range where titanium fails.

Under stress, titanium has failed in trichloroethylene containing a trace of water. Hydrochloric acid formed by hydrolysis is believed responsible for the attack. Laboratory experiments have shown that hydrochloric acid will attack the beta phase in an alloy high in alpha phase when it is under stress.

Galvanic couples: The corrosion rate of titanium normally is not increased when it is galvanically coupled to other metals. In sea water, metallic contact with titanium increases the corrosion rates of magnesium and aluminum alloys and mild steel: there is slightly increased attack on brass and cupro nickel, but high-nickel alloys or stainless steel are not significantly affected.

When wear and corrosion are combined, titanium may be a poor choice. Since titanium has a tendency to gall, valves and other such devices should be designed, if possible, to avoid a sliding fit.

Summary

While over-all performance may dictate titanium, more attention to design or to changes in operating conditions will often allow a less costly material to be substituted. It may, in some cases, be cheaper to change the environment than to use this expensive material. With titanium, galvanic attack on the other metal is often a serious factor.

The competition from titanium has spurred interest in some older more established types of materials. For example, there are new alloys being developed in the nickel-base field and in the copper-base field which will be of interest to those who have material problems for chemical or marine service.

Numerous other metals are available for chemical and marine service. Titanium has many potential areas of usefulness, but much more large-scale plant experience is needed before use of titanium can be fully justified. Titanium, and its alloys in chemical and marine service, will continue to have competition from steel and its alloys, aluminum-base, copper-base, nickel-base, and special alloys, depending on the situation.

LIQUID METAL COOLING FOR CONSUTRODE MELTING

Experiments by TMCA over a two year period indicate that NaK cooling is both practical and safe for consumable-electrode arc furnaces.

by D. E. Cooper and E. D. Dilling

EXPLOSION hazard has always been a problem to melters of reactive metals. Development of a liquid metal cooling system which utilizes a sodium-potassium (NaK) alloy indicates that this may become a thing of the past. The NaK alloy, which has fluidity similar to water at room temperature, has proven safe and reliable in almost two years of operation at the Henderson, Nev., research melt shop of Titanium Metals Corp. of America (TMCA), which developed the process.

The principal advantage of the NaK system is elimination of the explosion hazard, thus avoiding the high cost and relative inconvenience of explosion-resistant vaults. System evaluation in routine melting of several hundred ingots up to 18 in. in diam shows: 1) Maintenance cost is minor; 2) Melted material is salvagable on crucible failure [any wetting by water of a hot ingot of reactive metal in conventional systems results in total loss of the ingot]; 3) Repair and alteration can be done by normal plant maintenance groups; 4) Crucibles can be interchanged by means of specially designed valves; 5) Potential safety problems engendered by NaK's own reactivity are overcome through proper system design; and 6) Operating procedures are similar to those for conventional systems.

Cooling system research

Consumable electrode melting of titanium has been the subject of intensive research at TMCA, with concentrated study directed toward methods for cooling the crucible.

Water, of course, became the first candidate for this cooling job. A water-cooling system is deceptively simple in appearance. Actually, in operation, many details of the system turn out to be extremely critical because: 1) the electric arc represents an extremely concentrated form of energy which operates at extremely high temperatures, making the possibility of a perforated crucible ever-present; and 2) many molten metals, such as titanium, may react violently on contact with water.

To minimize the chance of crucible failure, adequate water flow must be maintained to every square inch of the crucible during melting. This means that the entrance of water, obstructing flanges, and spaces for steam pockets to develop are carefully considered in design and operation. Failure-safe instrumentation is provided to assure a steady flow of water for cooling in the event the main system fails, since a large quantity of sensible heat remains in the ingot upon termination of melting power. Methods of aligning the electrode and arc control methods, are also provided. And finally, since all means of protecting against the possibility of a crucible arc-through are subject to human and mechanical error, protection is provided against crucible failure and the potentially hazardous explosion itself by use of protective vaults.

The use of a liquid metal coolant, replacing water, would eliminate the potential hazard. A preliminary apparatus was, thus, set up for testing NaK cooling. It consisted of a 12-in. crucible especially designed for NaK, an electromagnetic pump, an electromagnetic flow meter, a water-cooled heat exchanger, and other necessary accessories. These were arranged in a closed loop system, as shown in Fig. 1. On the basis of four successful 350-lb heats melted at a maximum of 7000 amp, NaK cooling was considered to be adaptable to the furnace cooling problem.

The decision was then made to enlarge and perfect the system to include several furnaces in the TMAC Melting Research div. This was based on the objective of piloting a larger-scale system and of providing a safe system for melting research which would eliminate the need for vault protection, since vaults would limit the value of these furnaces for research purposes. Both of these objectives have been accomplished.

Design and installation

A general view of the facility is shown in Fig. 2. The furnace at the left is used for making small ingots. Larger ingots are made in crucibles, which are placed in a line on the operating platform. The electrode feed unit, shown at the right (on the floor), can be used on any of a number of crucible sizes. A vacuum manifold (the large pipe over the man's head, running across the picture) provides evacuating means to each furnace position. The furnace controls are nearby, on the platform. The dc current bus is attached to the wall above the platform. The essential NaK piping is underneath the platform.

A general understanding of the operation of the NaK cooling system can best be achieved by reference to Fig. 3. The NaK is distributed from one end of the melt shop to the other through a manifold

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pipe. The top pipe is the hot side of the manifold; the bottom side is cold. The electromagnetic pump draws NaK from the hot side of the manifold and drives it through the air-cooled heat exchanger. From the heat exchanger, it goes back to the cold side of the manifold.

Valves between the crucible and the manifold serve two purposes: 1) To block the crucibles which are not being used from the line; and 2) As disconnects to allow removal of the crucibles from NaK lines.

An expansion tank is provided at the top of the system to allow for expansion on heating and to provide continuous indication that the system is full. This latter function is performed by a series of probes which sense the NaK level and indicate this level on the control panel by signal lights.

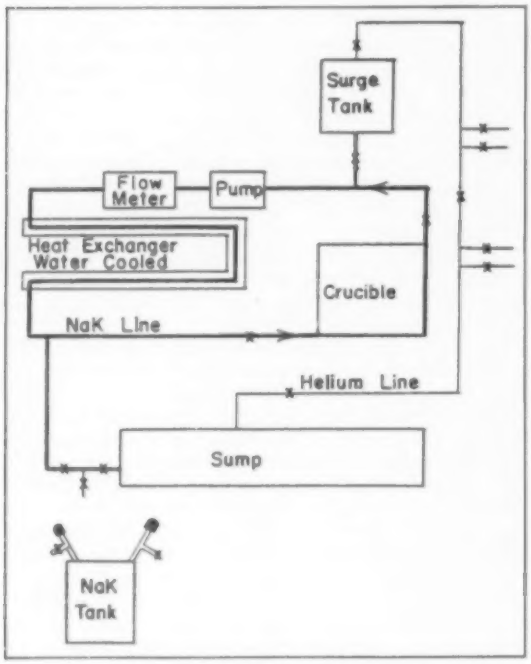

Fig. 1—The first NaK cooling system.

The sump tank serves as a reservoir into which NaK could be dumped in case of a leak in the lines. An inert gas blanket provides pressure equalization in the system to facilitate rapid dumping of the NaK into the sump tank. The slope of the manifold lines in the drawing illustrates the pitch of the pipes, which facilitate drainage. Controls for dumping NaK into the sump tank should be remote from the working area.

A steady and adequate circulation of liquid metal must be supplied to the crucible at all times during the melting, and for a sufficient time after melting power is terminated to cool the ingot to a safe temperature. The control system which accomplishes this failure-safe is shown schematically in the block diagram in Fig. 4. The power from the general plant supply is fed to the electromagnetic pump through a power-stat, which allows for adjustment of the pumping rate. A relay is attached to the plant power line. If the plant power fails, this relay actuates an automatic starter on a gasoline generator. In a matter of seconds, power is restored.

All controls for operating the NaK system and furnaces were placed on a control panel near the furnaces to facilitate study of furnace operation. Control panels, shown in Fig. 2, can be remote if desirable, but the use of NaK as a coolant obviates the necessity of a remote furnace control panel. However, since the fumes from burning NaK are corrosive, some form of fume-tight enclosure may be required in plant installations.

Performance

To date, several hundred melts, ranging in size from 5 to 18 in. diam, have been made using NaK cooling.

The air-cooled heat exchanger was found satisfactory for its design limit. But when shop facilities were expanded to utilize more melting power and make larger ingots, it was necessary to increase the cooling capacity. This was done by the arbitrary choice of the water-cooled heat exchanger in addition to the air-cooled one. This system works satisfactorily, but water-cooled heat exchangers would not be recommended for plant installations. The air-cooled heat exchanger alone is used for melts up to 12 in. diam. Air-cooled and water-cooled heat exchangers are used in series for larger melts.

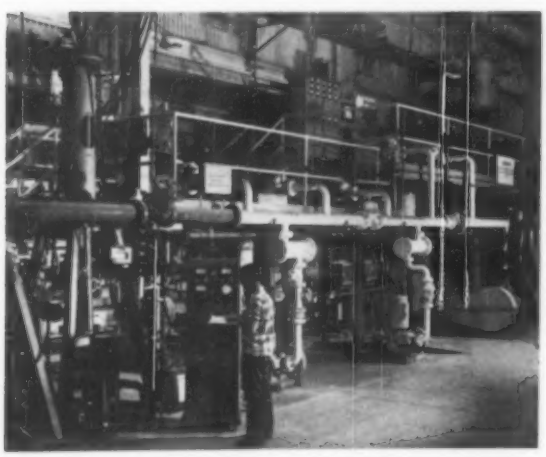

Fig. 2—General view of research melt shop.

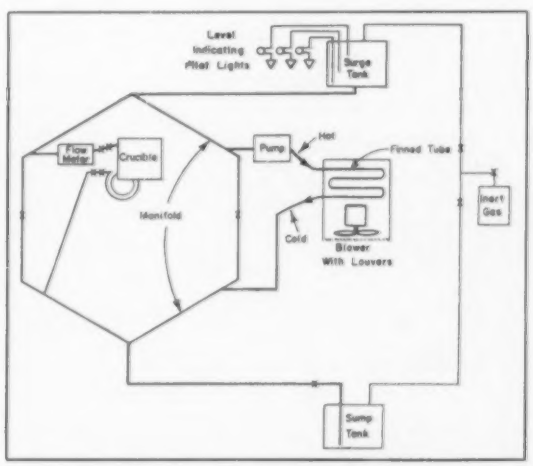

Fig. 3—Piping diagram of existing NaK system.

Routine operation of the melt shop is unimpaired by the use of a NaK system. It was found desirable to leave the crucibles in place; however, with valves of special design, they are removed with ease when necessary.

Repair and alteration of the cooling system is somewhat more difficult than with a water system, but it is nonetheless very practical. The NaK is drained into the sump tank, and a blanket of inert gas is maintained in the pipes while they are being sawed. If the opening is to remain for an extended period, it is plugged with a rubber stopper. When the pipe is to be rewelded, it is cleaned internally for a short distance of 3 to 6 in. by use of alcohol-soaked swabs. Welding is performed without difficulty.

Safety considerations

The NaK piping system was constructed with all welded joints as far as possible to avoid leakage which might develop in gasketed joints. Welds which appear sound may develop leaks in time because of the attack of NaK on slag inclusions. To minimize this potential hazard, the welded joints are covered with asbestos insulation. If a leak should develop, it can be detected by smoke from the asbestos-covered area.

The main object of using NaK as the heat exchange medium in titanium melting is to avoid furnace explosions upon crucible arc-through. A crucible arc-through is defined as a perforation in the crucible wall caused by the electric arc. A perforation will allow the coolant fluid to enter the melt zone, where a sizable quantity of liquid titanium is present along with the highly concentrated arc heat source. Several explosions throughout the industry, resulting from such crucible arc-throughs using water-cooling, demonstrate the potential hazard of that cooling method.

Liquid metal should not cause such an explosion upon a crucible arc-through, since no chemical reaction is believed possible between the liquid metal of the coolant and the liquid titanium. However, a pressure rise might be expected since the vapor pressure of NaK at the melting point of titanium is quite high, approximately 20 times atmospheric pressure. It must be remembered, on the other hand, that the pressure in a vessel containing vapors is controlled by the vapor pressure at the coldest point in the vessel. The vapor pressure of NaK at 441°F is of the order of 1.5 μ. Therefore, under normal operating conditions, when the cooled portions of the furnace are 400°F or less, there can be no appreciable pressure rise.

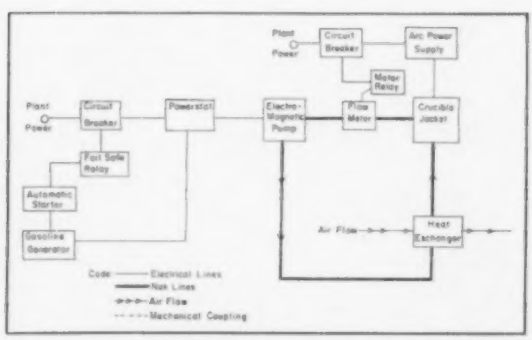

Fig. 4—The NaK flow control system.

Crucible arc-through while using NaK

An arc-through occurred while using the present NaK system; it was the result of too small a clearance between the electrode attachment clamps and the side wall of the crucible, and occurred while the arc was operating at 30 v and 3700 amp. Presence of the NaK in the crucible was observed on a viewing screen by an operator as a smoke cloud. The arc voltage dropped in two steps to 13 v under the influence of the NaK vapors, and the arc current rose to 4100 amp. The arc was terminated 12 sec after the arc-through occurred. The normal furnace pressure before the arc-through was 500 μ, and a furnace pressure of 250 μ was measured within 10 sec after the melting power was turned off. This confirms the theoretical prediction, indicated above, that there should be no pressure rise in the furnace.

The NaK flow was maintained for a period of several minutes to allow the ingot to cool. During this time, the furnace filled with NaK to within 8 to 10 in. of the side viewing port. The NaK flow was then terminated, and the major portion of the NaK was siphoned from the furnace interior into the standard NaK container. The ingot was then removed from the furnace, and the remaining NaK collected in a drip pan. The crucible cooling jacket was completely drained, and the arc-through hole was repaired. This repair work was accomplished from the inside of the crucible without removal of the cooling jacket. Since conventional brazing compounds containing silver are not suitable for direct contact with NaK, an overlay of nickel-base braze material was placed at the bottom of the hole, completely closing it. Then the repair was completed with normal brazing material.

An effort was made to determine the extent of contamination of the ingot bathed in NaK. Upon sectioning, a thin layer of approximately 50 mils depth was noted as having a different appearance from the rest of the ingot. However, on chemical analysis of drilled samples, the presence of sodium or potassium could not be detected. Thus, any contamination would be removed in ingot or billet conditioning. If water had been used, the ingot would have been a total loss.

Cost of NaK system

Cost comparisons with water systems are difficult because of the multitude of ways either system can be designed. An examination of water usage on a water-cooled system which does not recirculate the water shows that, where water costs are high, cost of the NaK system can be repaid in a few years by water savings alone. Where a recirculation system is used, the NaK system may appear favorable from the standpoint of the original investment and maintenance or operating costs.

Installation cost of a NaK system is comparable to a water system when the cost of vaults is included. The danger of loss of equipment and valuable melting stock is always present with water cooling. The NaK system eliminates such danger, and should, therefore, prove to be more economical in the long-run. As an example, the loss of a 2000-lb ingot of columbium—even if it was just wetted without an explosion—would pay for the NaK system. Therefore, when a new melting facility is planned, it may be wise to consider the NaK system from the standpoint of economics, in addition to the improved safety features.

ELECTRIC FURNACES, CLEVELAND, AND SUNSHINE

THE JOURNAL OF METALS does not hire a weather prophet. But a December cover with snow did seem more fitting than a splendid blaze of naked sunshine. And, occasionally, it does snow in Cleveland!

But forgive us, fair city by the Cuyahoga, for before all the world we must declare that the sun did shine, and brilliantly for the 17th Annual Electric Furnace Conference Dec. 2-4.

And the meet got off to a good start with the largest registration in the history of the conference . . . 1082. But numbers aren't the whole story, and in the ensuing paragraphs we depict reasons for the success of the conference . . . from the technical sessions . . . to the banquet and social events . . . and on to the plant trips.

Electric furnace committees

First event of the conference took place on the eve of its official opening—the dinner and business meeting of the electric furnace committees. The occasion was marked by P. R. Gouwens taking over the chairmanship of the Executive Committee from A. C. Ogan. New appointments to the Executive Committee were R. W. Farley, H. O. Beaver, S. O. Smith, R. Thompson and W. M. Kelly. The Conference Committee chairmanship was transferred from P. R. Gouwens to the former vice-chairman, G. C. Olsen. Other new members of the Conference Committee are C. G. Mickelson, Frank St. Vincent, B. H. Brown, Bert Troy, W. E. Brandt, and G. D. Lawrence. The nominations were unanimously approved by a vote of the Executive Committee. Upon a motion made, seconded, and carried, a vote of thanks was extended to those retiring from the Executive and Conference committees: V. E. Zang, J. H. Bischoff, C. B. Williams, R. K. Kulp, J. W. Tibbits, and O. K. Hill.

Consumable electrode melting

Technical sessions got underway on Wednesday morning, Dec. 2nd, following welcoming remarks by P. R. Gouwens, chairman of the Committee for the 17th Annual Conference. Registrants first interested themselves in a session on Consumable Electrode Melting, which was arranged by the Physical Chemistry of Steelmaking Committee. Few vacant seats could be found in the ballroom of the Cleveland Hotel for this session, which considered this development now making rapid strides in steel melting beyond its initial domain of reactive metals.

W. J. Childs of Rensselaer Polytechnic Institute described *European Developments in Consumable Electrode Melting*. He pointed out the considerable interest consumable electrode melting elicits in Europe. Germany has been building large-scale furnaces (see JOURNAL OF METALS, March 1958, pp. 193 to 198), although there has been a lag in installations there due to the dormant state of her aircraft industry. Nevertheless, installations have been made, and the author showed a slide of a small furnace at the Deutsche Edelstahlwerke. In the UK, many of the steel companies are doing development work in this field, although only one installation is actually in operation on steel. While the Bofors plant in Sweden has the largest consumable electrode furnace . . . capable of producing 6-ton ingots . . . the author found the most impressive plant to be that of Imperial Chemical Industries in Birmingham, England. It is largely being used to melt titanium sponge produced by the sodium reduction process, but the furnaces are finding increasing usage in melting steels on a custom basis. European consumable-electrode melting furnaces are being used for beryllium, zirconium, and other reactive metals, but they have not gone as far as the US in melting uranium fuel elements.

The second paper on the program was *Electrical Behavior of Consumable Electrode Arcs in Variable Pressure Systems* by T. E. Butler and R. P. Morgan of Union Carbide Metals Co. The authors called attention to unstable arc behavior in reduced pressure systems. Such instability represents a potential source of problems, such as mold burn-through, electrode distortion, and disturbances in the uniformity of energy input. One requisite of an efficient melting operation is the provision of control procedures capable of recognizing this behavior in order that suitable corrective action may be applied.

The authors conducted an oscilloscopic study of the voltage characteristics of the consumable electrode arc under reduced pressure conditions and demonstrated the existence of transient fluctuations that define the operating mode of the discharge. A preliminary correlation between known modes of arc instability and these characteristics was used to

Electric Furnace Conferences are always times for renewing old friendships! At left . . . and from left to right . . . banquet toastmaster, D. R. Loughrey; Finance Committee Chairman, R. W. Dally; President Elect of The Metallurgical Society, Carleton C. Long; AIME President, Howard C. Pyle; and Metallurgical Society President, John Chipman. Below . . . from left to right . . . AIME Secretary, Ernest O. Kirkendall; Electric Furnace Executive Committee Chairman, P. R. Gouwens; former chairman, V. E. Zang; and Chairman of the AIME Cleveland section, F. A. Zorko.

analyze the behavior of the arc during the penetration of a number of conventional cold-mold ingots. At present, the amount of quantitative information available is limited. However, the authors concluded that control procedures, which are based upon the analysis of the instantaneous voltage signal, can be developed, and these have considerable practical potential.

S. J. Noesen of General Electric discussed *New Developments in the Consumable Electrode Melting of Reactive Metals.* Factors such as power input, temperature, metal vapor pressure, and electrode diameter which affect the quality of consumable electrode-melted reactive metals were considered. In a prepared discussion by E. W. Johnson of Westinghouse, comparisons were made between techniques for titanium and steel melting. Effective purification of steels by the consumable-electrode technique requires vacuum conditions, since thermal purification is not possible in the short period of time during which the metal passes through the arc. Mr. Johnson pointed out that under low-pressure conditions the arc does not have the same concentration of heat that it has under atmospheric pressure; thus, metal vapor pressure is not a major factor in steel melting, and there is only a slight superheat in the vicinity of the arc. Crucible geometry and electrode diameter are important in both types of melting, but for steel the variation of arc power has little effect on purification.

Consumable Electrode Melting of Steel and High-Temperature Alloys was discussed by R. C. Buehl and A. M. Aksoy of Crucible Steel. They called attention to the rapid expansion of this melting technique for steels during recent years, with 12 firms now engaged in production. Crucible Steel is producing ingots up to 32-in. diam, weighing 32,000 lb. And there is now a contract for construction of a furnace for 40-in. diam ingots. (See the Reporter item, p. 111). But Buehl and Aksoy cautioned on overoptimism on the expansion of consumable-electrode melting of lower alloy steels. While vacum-degassed steels are never as pure as consumable-electrode melted ingots, the degassing technique does have certain cost advantages.

Other sessions

Wednesday afternoon included three very interesting technical sessions: Refractories; Quality Control of Electric Furnace Melting; and Raw Materials and Special Alloys.

The Refractories session considered the question of castable electrode rings and roof construction. One of the papers presented in a last-minute substitution was that of C. E. Grigsby and W. F. Rappold of General Refractories. Entitled *Electric Furnace Refractories,* it originally appeared as the Phases and Processes column in the December issue of JOURNAL OF METALS. The Quality Control session included the paper *Effect of Various Deoxidizers on Cast Steel,* by

Dinner digesting (left), those attending the Annual Electric Furnace Banquet witnessed (below) P. R. Gouwens present a certificate of appreciation to past chairman of the Electric Furnace Executive Committee, A. C. Ogan, "for his outstanding contributions to the Electric Furnace Conference".

C. E. Sims of Battelle Memorial Institute and C. W. Briggs of the Steel Founders Society; it appeared under another title on pp. 815 to 822 of the December issue of JOURNAL OF METALS.

At this same session, a process for obtaining steel with less than 0.005 pct S was described by A. J. Kiesler and General Electric. The process takes advantage of the well-known increase in desulfurizing ability accompanying a high lime slag in the presence of high carbon and low FeO in the bath. The desulfurizing is done immediately following meltdown. The slag is removed, and the excess carbon oxidized by oxygen lancing. This process is the reverse of standard basic electric practice and is reportedly as economical as the former. A marked lowering of the impact-transition temperature is achieved through the reduction of sulfur to this level in 0.20 carbon steel.

At the Raw Materials and Special Alloys session L. H. Banning and W. A. Stickney of the Albany Metallurgical Research Center of the US Bureau of Mines discussed *Beneficiation of Domestic Chromium Ores*. Included was a summary of beneficiation studies, with particular reference to flotation of chromite pulps in the presence of slime and high-tension electrostatic processes for treating table middlings. One plant that employs electrostatic separations and another that uses tables were described. The authors concluded with remarks on the economics of chromium mining and ore treatment in the US.

Thursday sessions

A session on Degassing of Steels for Foundry Melting Practice included papers on ladle and ladle stream degassing, as well as vacuum degassing of steels for aircraft uses. W. F. Hipple of Ajax Magnethermic Corp. detailed *Equipment for Vacuum Degassing in the Foundry*. He pointed out that vacuum

melting and casting techniques are too costly for wide application in the foundry industry, but that small ladle degassing units have recently been designed. These will permit a profitable process and a much better casting.

In a session on Construction and Tool Steels, W. H. Burr of the Duquesne works of U.S. Steel Corp. presented a paper on the *Correlation Between Tap Temperatures, Ladle Temperatures, and Pouring Stream Temperatures.* He pointed out that a program to determine the pattern of temperature losses during tapping and pouring of electric furnace heats is currently in progress. The ultimate objective is to determine whether or not pouring stream temperatures can be employed to predict the internal quality of resulting products. More will probably be heard of this work when it is completed.

On this same theme, N. W. Samways and T. E. Dancy of Jones & Laughlin presented a paper entitled *Factors Affecting Temperature Drop Between Tapping and Teeming.* In it they concluded that probable temperature change can be determined from detailed statistical analyses of measured tapping and teeming temperatures in open-hearth and basic-oxygen (LD) shops, together with heat balance calculations of the effect of ladle additions and an independent theoretical treament of heat losses to ladle walls. No measurements were taken in an electric-furnace shop, but the method developed for estimating temperature drop is of general application to all types of furnaces. This is an indirect method, because the inconsistent form of the metal stream prevents a theoretical estimation of the heat loss from the tapping stream. Furthermore, the heat effects due to ladle alloying additions can not be calculated unless the reaction mechanism is known. The effect of the tapping stream on the temperature was, thus, determined by the difference between the theoretical temperature drop due to heat loss to the ladle walls and the overall temperature drop determined statistically (including terms for tapping, hold time, teeming time, and three alternative ladle addition reaction mechanisms). The best correlation was taken as indicative of an acceptable ladle reaction mechanism. JOURNAL OF METALS expects to present this paper in a forthcoming issue.

G. W. Hinds and A. L. Hodge of Linde Co. described *The Use of Oxygen-Fuel Gas Burners for Scrap Meltdown in Electric Furnaces.* They pointed out the following important advantages stemming from this process: production increased from 15 to 20 pct, power consumption decreased an equal amount, and uniform scrap melting rates.

An important session on Thursday afternoon was devoted to stainless steels. One of the several papers was that on *The Use of Special Additives in Stainless Alloy Steels*, presented by A. J. Nimeth of Jones & Laughlin. He pointed out that the Stainless and Strip div. of J&L in Detroit has developed a technique for removing gas by additions of lithium to the furnace and then to the ladle; two-ounce additions of 99.8 pct Li are used in each treatment. Furnace injections of lithium and purging with argon are made until there is no visible indication of gas present. Lithium is again added to the ladle after it has been filled to about two-thirds of capacity. Mr. Nimeth reported the technique's success in melts of type 430 stainless; trials with other grades are continuing.

Another paper presented at this session was that entitled *Practical Economics in Stainless Steel Melting*, by R. B. Shaw of Allegheny Ludlum. It was published on pp. 823 to 828 of the December issue of JOURNAL OF METALS.

The annual dinner

Resounding to a combo's strains of "Alabamy Bound" and "California Here I Come," the ballroom of the Cleveland Hotel welcomed electric-furnace men pouring in from the reception and cocktail party. Soon well filled with roast prime rib of beef au jus, the men settled back to hear P. R. Gouwens, conference chairman, open the evening by giving thanks to retiring chairman, A. C. Ogan, for his long and distinguished service to the Electric Furnace Committee. He was presented a lifetime registration card, a certificate of appreciation, and an atmospheric clock. Accepting these tokens of appreciation, Al Ogan, in turn, thanked conference chairman Gouwens, for his work in organizing such an excellent conference. He then introduced D. R. Loughrey, toastmaster of the evening. Dan Loughrey referred to his associations with the puddlers (open-hearth men), the cokesackers (coke-oven men), the windjammers (blast-furnace men), and especially his great friends the sparkies (electric-furnace men). The metallurgists came in for their share of good-natured criticism.

Dr. John Chipman, President of The Metallurgical Society, was introduced. He remarked that the prototype of successful AIME conferences was established in the 1920s under the leadership of Leo F. Reinartz, who organized the National Open Hearth Steel Conferences. In those days, it was "hard to get people to talk." The Electric Furnace Conferences have followed the same pattern, and their success is illustrated by the fact that "it is now difficult to get people to stop talking."

Howard C. Pyle, President of the AIME, was introduced and commented on the increased service to members of AIME through meetings and publications that have been made possible through organization of the constituent societies of AIME.

The speaker of the evening, William E. Umstattd, chairman of the Executive Committee of Timken Roller Bearing Co., was introduced. He discussed his ideas of *Foreign Trade.*

Plant trips

Friday, December 4th, was devoted to plant trips, and registrants had a choice of visiting either the Canton plant of Republic Steel Corp. or the Barberton plant of Babcock & Wilcox Co.

The first of these trips emphasized the electric furnace shop, where visitors saw furnaces being charged and tapped, as well as the operation of an induction stirrer. Luncheon was served at the Town and Country Restaurant in Canton, courtesy of Republic Steel Corp.

The Babcock & Wilcox plant is a part of the firm's Boiler div. Facilities visited included the pierce and bar shop, the alloy and iron foundry, the machine shop and tool room, the sheet and structural shop, and other operations. Luncheon was served in the plant cafeteria.

Registrants were returned to the Cleveland Hotel by about 4:30 pm and from there made their way home . . . perhaps a little tired . . . but nevertheless certain that this was the best conference ever! FWS

RIMMED STEEL MAGNETIC SHEETS... How they were produced for the Proton Synchrotron.

An outline of the manufacturing procedure and magnetic properties of steel sheet being used for the construction of magnetic blocks in the 25-bev proton synchrotron of the European Organization for Nuclear Research . . . CERN . . . at Geneva, Switzerland. CERN and its research program were described in an article appearing in the November 1958 issue of JOURNAL OF METALS.

by G. Odone and B. Sommacal

QUALITY and uniformity standards for the steel sheet being used in the construction of the 25-bev proton synchrotron near Geneva, Switzerland, imposed a serious problem upon the steel producer. For economic reasons, preference was given to soft, rimmed-steel sheet, but the magnetic properties of such steel sheet, as obtained by normal production procedures, do not meet the standards which were established. It was, therefore, necessary to develop a new manufacturing procedure which would provide the required properties for this steel sheet.

In due course, an order for 4000 metric tons of low-carbon rimmed steel sheet was entered at the Cornigliano steel plant. The size of these sheets in mm was prescribed as: 1.5x1000x1200. This totaled approximately 300,000 sheets.

Magnetic specifications for this order were as follows:

1) Coercitivity not to exceed 1.5 oersted for any lift (one lift per ingot);

2) Coercitivity of any one lift not to vary by more than + or − 0.1 oersted in relation to the average coercitivity of the entire order;

3) Permeability to be greater than 400 at an induction of 100 gauss, greater than 700 at an induction of 15,000 gauss, and greater than 60 at an induction of 20,000 gauss; and

4) Maximum uniformity of permeability.

It was evident that it would be impossible to obtain these magnetic properties through normal production procedures for soft rimmed steel. The coercitivity value for this type of steel is, in fact, 1.8 oersted and above. Such steel shows permeability values which are acceptable for average and high induction values, but permeability at lower induction levels is less satisfactory. Thus, efforts were undertaken to devise new procedures which would allow for the production of low-coercivity value sheet.

G. ODONE and B. SOMMACAL are research and quality-control supt., and supv. research metallurgist at Cornigliano SpA, Genova, Italy.

A study of the relationship between steel structure and coercitivity showed that it was necessary to produce a soft rimmed-steel sheet with a uniformly large grain structure. With this type of grain structure, the deleterious effect of grain boundaries on some magnetic properties, including coercitivity, is reduced.

A greatly pronounced grain growth may be obtained by many means, but at Cornigliano we considered only that procedure best suited to plant equipment and type of production. This procedure essentially consists of subjecting cold-rolled annealed strip to a slight cold reduction, and then subjecting it to a final annealing process.

The practical compilation of the procedure was preceded by a series of laboratory tests to fully evaluate the extent of grain growth as determined by: the most suitable percentage of cold reduction, the temperature and length of soaking period of the last annealing process, and the most suitable grain structure of the starting cold-reduced annealed strip.

Various cold reduction rates—from a minimum of 2 pct to a maximum of 20 pct—were studied. For each of these rates annealing cycles of different temperature and soaking periods were adopted. The choice of laboratory annealing cycles was determined by their adaptability to the plant annealing equipment.

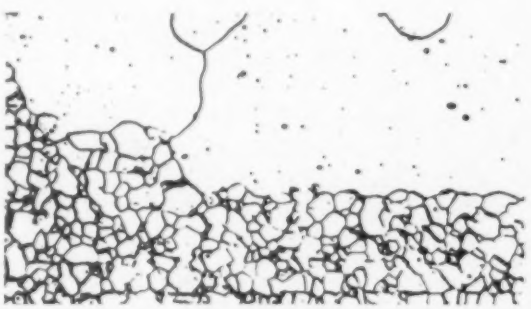

Fig. 1—Rim zone of cold-reduced, soft, rimmed strip, subjected to a light cold reduction and then annealed. X100.

Results of tests

The results of these laboratory tests may be summarized as follows:

1) Grain growth in a cold-reduced, soft, rimmed strip, which has been subjected to a light cold reduction and then annealed, starts in the zone lowest in carbon, i.e., the rim zone—See Fig. 1;

2) The greater the degree of cold reduction, the lower the final annealing temperature at which grain growth becomes apparent; and

3) Grain growth achieves its maximum size at a cold reduction of 4 pct.

Figs. 2 and 3 depict the granular structures obtained by 6, and 10 pct cold reduction, respectively, and a final annealing soak of 8 hr at 720°C. For cold reduction of less than 4 pct, the grain growth is not completed with any of the experimental annealing treatments, and the structures are similar to that illustrated in Fig. 1.

In order to achieve a highly uniform grain growth together with a large increase in grain size, we decided upon a cold reduction rate of 5 to 6 pct, which is a little higher than the 4 pct rate corresponding to the maximum growth.

As a last step we studied the effect of the grain size of the starting strip upon the grain structure of the finished sheet. This part of our laboratory studies indicated the advantage of the first annealing cycle for the starting strip to be such as to result in an ASTM grain size of five prior to the subsequent cold reduction of the strip.

Plant procedure established

On the basis of the laboratory tests, the new manufacturing procedure was established. This was tested on a mill production basis in order to evaluate its practicality and to study the characteristics of the final product.

The slight cold reduction of mill pilot lots was obtained by skinpassing the material on the temper mill; results have been satisfactory. Confirming laboratory tests, the magnetic characteristics were greatly improved, and shipment of the sheet ordered for the magnetic blocks of the proton synchrotron was begun.

The procedure followed for the production of the sheet for the completed order was as follows:

Soft rimmed steel of the following ladle analysis was used: 0.08 pct C max, 0.25 to 0.45 pct Mn, 0.030 pct S max, and 0.015 pct P max. The resulting ingot was passed through the following sequence of operations: hot rolled into coils, pickled, cold reduced up to 60 pct, annealed in coil form to 720°C and soaked for 24 hr in controlled atmosphere, skinpassed to produce a further cold reduction of 5 to 6 pct, sheared to sheet size, annealed in sheet form at 720°C and soaked for 24 hr in controlled atmosphere, inspected, and oiled.

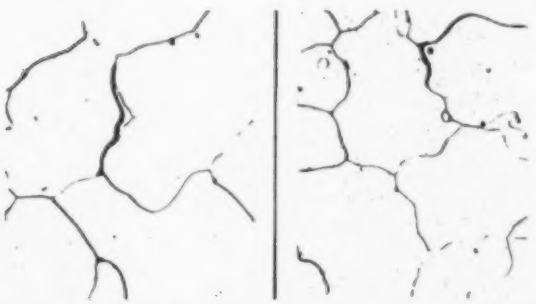

Fig. 2 (left) and 3 (right)—Granular structures obtained by 7 and 10 pct cold reduction, respectively, and a final annealing soak of 8 hr at 720°C. X100.

Results

The average magnetic properties of the sheet supplied for the proton synchrotron blocks were superior to those prescribed in the order, and precisely: 0.83 oersted conductivity, permeability of 590 at 100 gauss, permeability of 1179 at 15,000 gauss, and a permeability of 80 at 20,000 gauss. The uniformity of the material supplied also proved to be satisfactory.

Tables I and II, complete the information about the magnetic properties of the sheet supplied to the CERN proton synchrotron. Table I lists the values of the permeability as a function of the induction and magnetizing field, while Table II lists the values of the coercitive force and of the remanence as a function of the initial induction.

Among the results obtained with this order was the remarkable low coercitivity. It is particularly obvious when compared to that of the same type of steel processed according to the normal plant procedure. Table III shows the total magnetic losses of the normally-produced cold-rolled sheet for various gages at a frequency of 50 Hz and an induction of 10,000 gauss. And even the results shown in Table III may be considered remarkable, since the electrical resistivity of this material is only 0.12 ohm mm^2 per m, i.e., almost equal to that of industrially pure iron.

Table I. Permeability as a Function of Induction and Magnetizing Field for Sheet Supplied to Proton Synchrotron.

Induction, Gauss	Magnetizing Field, Oersted	Permeability
100	0.16	590
1,000	0.58	1,724
4,000	1.05	3,809
6,000	1.35	4,444
8,000	1.95	4,102
10,000	2.80	3,571
15,000	12.72	1,179
20,000	250.00	80

Table II. Coercitive Force and Remanence as a Function of Initial Induction for Sheet Supplied for Proton Synchrotron.

Initial Induction, Gauss	Coercitive Force, Oersted	Remanence, Gauss
1,000	0.215	800
5,000	0.59	4,000
10,000	0.79	7,400
13,700	0.81	8,800
17,500	0.82	8,900
20,000	0.825	8,900

Table III. Magnetic Losses at 50 Hz Frequency and 10,000 Gauss for Normally Produced Cold Rolled Sheet at Cornigliano.

Thickness, mm	Loss, Watt per kg
0.5	2.95
0.6	3.50
0.7	4.25
0.8	4.80
0.9	5.70
1.0	6.60

Phases and Processes

HIGHLIGHTING CURRENT DEVELOPMENTS IN METALS

High Temperature Materials

by R. W. Guard, General Electric Research Laboratory

As the required temperatures for rocket and missile applications increase, it is obvious that refractory metals such as molybdenum, columbium, and tungsten will become important. Together with this we are finding more exacting requirements placed on the older more familiar nickel and cobalt-base superalloys. These materials are being produced to meet the design needs today as they were 10 to 15 years ago. Eight years ago, the standard turbine bucket alloy was used at 1475° to 1525°F. Today alloys are available for service above 1700°F. This increase is the result of a better understanding of the materials themselves and a better knowledge of the properties required for adequate service.

Our understanding of the materials has been increased by an analysis of the relation of microstructure and properties in commercial alloys and a synthesis of the knowledge gained from the study in simple systems. An example of this kind of analysis is shown in a series of papers by J. Glen.[1,2,3] In many commercial alloys he shows that the strengthening (as shown by a reduction in creep rate) can be traced to precipitation reactions (or transformations of the precipitated phases). He demonstrates that the regularities in these reactions permit more accurate extrapolation of short-time data than the usual methods. In addition to this, it follows that by changing the rate of transformation or precipitation or by causing another reaction to take place, one can make an alloy with superior long-time properties. While this principle has been anticipated by other workers, Glen's work demonstrates the results on commercial alloys.

Extrapolation methods, which have found favor previously, have again been examined by Goldhoff.[4] His conclusions are of interest since he has dealt most specifically with the use of parameters in extrapolation for very long times. Somewhat disconcertingly, he finds that often the more precise the parameter used the lower the extrapolated strengths at long times. While most of his data are for ferritic steels, the same effect may exist for austenitic materials as well.

While we can not claim that Al-Cu alloys are superalloys, a recent report [5] on their high temperature behavior might shed some light on a problem now being encountered in some short-time applications. What happens when an age-hardened alloy is heated above the solvus temperature? Because diffusion is relatively slow the precipitate may persist for a short time. The rate of solution (and the loss in strength accompanying solution) are influenced by stress and particle size as well as the amount of *overtemperature*. Simultaneous straining can inhibit the dissolution process at least in the early stages. Further study of this process may permit the design of alloys for particular applications involving short life but requiring reasonable strength.

SAP-type materials

When it was first discovered a decade ago that cold-worked aluminum powder bars retained their strength considerably above the usual recrystallization temperature, much hope was expressed in the use of this principle for giving remarkable strengths to other materials. It has since been demonstrated that a fine dispersion of Al_2O_3 coming from the surface skin on the powder is responsible for the unusual properties. Although much work has been expended on SAP-type alloys, only moderate success has been achieved in other systems. It appears that the important characteristics of this kind of material are a) a very fine and stable metal particle size;[6,7] b) a stable dispersed phase;[8] and c) the proper interparticle distance.[9] In any system both composition and processing must be controlled to optimize all three factors. One method of obtaining items a) and c) is by internal oxidation of very fine alloy powders.

Russian notes

In a recent article in the JOURNAL OF METALS[10] some of the Soviet research in high temperature strengthening was reviewed. A few additional remarks on people, places, and things seem appropriate. The A. A. Baikov Institute now publishes a yearly volume entitled *Investigations of Heat Resistant Alloys*.[11] This publication is a broad coverage of both fundamental and applied research. Volume III has 46 papers totaling 428 pp. covering such diverse subjects as *Self Diffusion in Iron*, *The Structure of Chromium Carbonitrides*, *The Cr-Nb-Va Constitution Diagram* and *X-ray Spectroscopic Studies in Fe-Mo and Fe-Al Alloys*. The contents do not suggest any significant change in the directions of their work. There is still a great deal of work on the relation of X-ray spectra and bond strength and diffusion and heat resistance. There are few direct references to commercial materials. We can infer from their work, however, that they face much the same problems we do in this country.

Two other research groups working on related research are the Leningrad Polytechnic Institute where Zhurkov and Stepanov are working on the effect of temperature on deformation and the Ukrainian Academy Institute for Metal Physics under Dekhtyar where work on the relation of diffusion and deformation is being carried out. In the next column of Phases and Processes devoted to high temperature materials, the latest Soviet work will be reviewed in more detail.

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Ferrous Metallurgy

by W. C. Leslie, U.S. Steel Research Center

Columbium in ferritic steels

Among the more interesting recent developments in ferrous physical metallurgy is the use of small additions of columbium to semi-killed low- and medium-carbon steels. The additions are generally in the range of ¼ to ½ lb per ton of steel. The effects of these additions on microstructures and mechanical properties have been discussed by C. A. Beiser in ASM 1959 preprint No. 138, reviewed in *Metal Progress*, Nov. 1959. The ferrite grain size in 0.20 pct C plates, hot-rolled or normalized, can be reduced about one ASTM number by a columbium content of 0.03 pct. Greater concentrations produce little additional refinement. The 0.2 pct offset yield strength of hot-rolled plates was increased about 5000 psi for each 0.01 pct of recovered columbium, and again, the initial increments were most effective. Above about 0.04 pct Cb, there was little additional increase in yield strength. The ultimate tensile strength increased about 3000 psi for each 0.01 pct Cb, in the same range. The elongation and reduction of area were slightly reduced. In the normalized condition, the increase in yield strength was about 3000 psi per 0.01 pct Cb, and the tensile strength remained unchanged. The elongation and reduction of area were slightly increased.

The Charpy V-notch 15 ft-lb transition temperature of hot-rolled steels was raised about 12°F for each 0.01 pct Cb, up to about 0.04 pct—rather surprising in view of the accompanying reduction in ferrite grain size. The increase in transition temperature continued with increasing columbium additions, but at a slower rate. Electron micrographs revealed an almost continuous network of grain-boundary carbide films in the hot-rolled plates, which might explain the decreased notch-toughness, but these films did not appear in normalized plates in which notch-toughness was improved by the columbium addition.

Analysis of carbides separated from these steels showed them to be enriched in columbium and nitrogen. Absorption of nitrogen into the carbide phase will affect strain-aging behavior. The extent of such effects will probably depend upon the columbium content and the thermal history of the steels.

Unless economical means can be devised to eliminate the detrimental effect of columbium on notch-toughness of hot-rolled plate steels, it is likely that columbium-treated steels will be used principally in sheet form, for which impact properties are less important.

Open-coil annealing

Although the economics of the process have yet to be proved by large-scale production, the possibilities inherent in the open-coil annealing process are truly intriguing. In this process, coils of cold-rolled steel are recoiled with a thin cord between the windings. When the cord is withdrawn, spaces are left between the windings, and the annealing gas can make intimate contact with all parts of the coil. In the continuous annealing process the cold-rolled strip is in intimate contact with the annealing atmosphere, but only for a limited period. In conventional box annealing, as shown by R. M. Hudson and G. L. Stragand in ASM 1959 preprint No. 150, the composition of the furnace gas differs from that of the gas supplied to the furnace, and the gas within the tight windings of the coils is different from both of the others. From the standpoint of controlled processing, both continuous annealing and box annealing leave something to be desired.

The open-coil annealing process offers the following advantages:

1. Close control of the composition of the annealing gas in contact with the steel, and complete exposure of the steel to the atmosphere;
2. Close control of annealing temperature over a wide range;
3. Rapid heating and cooling; and
4. A wide choice of annealing cycles.

Control which formerly could only be exercised in the laboratory may perhaps be applied to high-tonnage production. Thus, we may see commercial sheets containing vanishingly small amounts of carbon and nitrogen, with all that entails. There appear to be excellent prospects for improvement of present flat-rolled products and for the development of new products with unusual properties.

Properties of high-purity iron-carbon alloys

Extensive work on the mechanical properties of high-purity iron-carbon alloys done at the University of Pennsylvania has been summarized by R. M. Brick in Report SSC-94, Mar. 31, 1959, of the Ship Structure Committee, transmitted through the National Academy of Sciences. True stress-true strain tests of iron containing 0.02 to 0.49 pct C at temperatures from—185° to 23°C, indicated that yield strengths and flow stresses increase continuously with increasing carbon and with decreasing temperature. The grain size was constant at about ASTM 4. Fracture stresses also increased with decreasing temperature, at least until the tensile transition temperature was reached. Ductility at all temperatures decreased with increasing carbon content.

The ferrite grain size was varied in a series of alloys containing from 0.02 to 0.12 pct C. For an 0.02 pct C alloy, ferrite grain size was the factor which controlled ductility at low temperatures. For higher carbon contents, the ductility at liquid air temperatures was determined by both ferrite grain size and carbide distribution. Carbides precipitated in ferrite grain boundaries reduced ductility. Spheroidization of the carbides improved the total strain at liquid air temperatures. The strain hardening exponent decreased with increasing carbon content, with increasing ferrite grain size, and with decreasing temperature. Substructure, produced during the austenite-ferrite transformation, increased the yield strength at low temperatures.

Some interesting results were obtained in a study of the V-notch Charpy impact behavior of alloys containing 0.003 to 0.03 pct C. Precipitation of carbides in the 400° to 700°C range caused a decrease in hardness and yield strength, but an increase in the impact transition temperature. Brick concluded that the precipitated carbide particles initiate cracks, but inasmuch as the transition becomes less abrupt, he also postulated that the particles inhibit crack propagation. Direct evidence to support this hypothesis may be difficult to obtain, but the effort is probably justified. The transition temperature of ferrite with substructure was higher than that of ferrite with no substructure. The effect of substructure seems to be opposite to that of grain size. For alloys containing about 0.015 pct C, quenching from A_1 leads to a minimum in the impact transition temperature. This is similar to the results obtained by Josefsson (AIME, Trans., vol. 200, p. 652, 1954) on commercial steels with this carbon content).

Fall Meeting: Molybdenum and Tantalum Processes

MOLYBDENUM BY DIRECT THERMAL DISSOCIATION OF MOLYBDENUM DISULFIDE

A paper by D. V. Doane, W. G. Scholz and G. A. Timmons, Climax Molybdenum Co.

It has been known since before the turn of this century that a number of metals can be produced directly from their sulfides, merely by dissociating the sulfides with heat and simultaneously pumping off the evolved sulfur. This is a description of research in progress on the production of molybdenum by thermally dissociating molybdenite which has been concentrated by the flotation process to lubricant-grade molybdenum disulfide.

While much work remains to be done, that which has already been accomplished has yielded promising results. Equipment for dissociating molybdenite has undergone several cycles of scaling-up and development. Work now in progress utilizes pilot scale equipment capable of dissociating 160-lb charges of pelletized molybdenite.

The pilot plant consists of a furnace (dissociation chamber) in which a pressure of about 1μ can be maintained while operating at a temperature of 3000°F. A sulfur condenser is located between the furnace and the vacuum pumps. The furnace is located within a chamber filled with purified argon so that if a vacuum seal should fail, only purified argon, which is harmless to the product, can leak into the furnace. Rubber gloves, fitted into one of the chamber openings, enable the operator to remove the product from the furnace, as well as to crush and bottle it while it is still in the purified argon atmosphere contained within the chamber. The bottled charge can be transported, charged into a consumable electrode arc-casting machine, and arc-cast without ever exposing it to air.

The metallic impurity content (determined by spectrographic analysis) of the arc-cast molybdenum was essentially the same as that of arc-cast molybdenum made from molybdenum powder reduced by hydrogen from ammonium molybdate which was made from sublimed molybdic oxide. Vacuum fusion analyses revealed that the contents of the interstitial elements (hydrogen, nitrogen and oxygen) of the arc-cast dissociation product were as low as those obtained in commercial arc-casting practice, and it is fully expected that this can be improved upon with the equipment now available.

One experimental ingot which was arc-cast from thermal dissociation product was adjudged to be the best arc-cast molybdenum which Climax has made on the basis that it exhibited the cleanest grain boundaries and the lowest carbon content of any arc-cast molybdenum heretofore examined.

TANTALUM METAL BY SELECTIVE SOLUTION

A paper by R. L. Baughman and D. F. Taylor, Fansteel Metallurgical Corp.

Early work on Ta alloys showed Ta and Al to form a rather stable crystalline material whose chemical analysis indicates the composition Al_3Ta. It has also been established that Al_3Ta is formed when K_2TaF_7 and aluminum are heated together. This investigation showed that when K_2TaF_7 and Al are heated together at about 1000°C, Al_3Ta is formed quantitatively. When the salt slag and excess aluminum are dissolved away, the resulting powder is a clean crystalline product whose analysis is 69.72 pct Ta, with only traces of other elements except Al. We have found that evaporation of Al from the Al_3Ta by heating in vacuum is difficult to accomplish. Compacted Al_3Ta melts before decomposing, and in liquid state reacts with all refractories used as containers. Further work showed that Ta is separated from Al_3Ta when Al_3Ta and Cu are heated together above the melting point of Cu. The ingot resulting from such reaction contains free Ta metal 97 to 98 pct pure dispersed in a Cu-Al alloy. This separation is apparently the result of the selective solution of the Al in Cu. Tantalum powder from Al_3Ta cannot, however, be sintered by the method normally used for electrolytic Ta powder. It is necessary to blend 5 pct Cu powder with the tantalum, and then sintering will effect a sound, workable bar. Ta bars so produced have been rolled into sheet and foil of good quality.

To summarize the process:

a) React K_2TaF_7 with Al at 1000°C in a graphite crucible.
b) Remove slag and excess Al with HCl.
c) Melt Cu (1100°C) in graphite crucible, add Al_3Ta, stir then cool.
d) Dissolve Cu-Al alloy from the Ta powder with acid.
e) Wash and dry powder.
f) The powder is blended with 5 wt pct Cu metal.
g) Compacted bars were sintered 2 hr at 2100°C, given a 30 pct reduction by rolling, and resintered two hours at 2100°C. One such bar was then rolled to 16 ft 0.005 x 2½ in. strip.

One of the smaller bars was rolled into .0017 in. sheet after sintering to further study the physical and chemical properties of this material. These properties are:

Physical

Tensile strength, psi	51,100
Elongation, 2 in. sample, pct	23.5
Elongation, 1 in. sample, pct	24.5
Surface	Uniform grain size
Sintered bar hardness R_B	72

Chemical analysis, pct

Fe	0.014
Mo	Less than 0.003
Cb	" " 0.01
Ti	" " 0.01
Si	" " 0.01
Al	" " 0.01
Ca	" " 0.01

This method seems to be sound, efficient, and suited to large-scale production-type equipment.

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METALLURGICAL SOCIETY OF AIME

NEWS

Annual Meeting Lecturers and Topics Listed

Speakers and topics for Annual Meeting lectures and luncheons have been announced by the three divisions of The Metallurgical Society.

Robert F. Mehl will deliver the Iron and Steel Division's annual Howe Memorial Lecture. His topic: *Commentary on Metallurgy*. Dr. Mehl will return from his recent appointment as scientific liaison between U. S. Steel Corp. and European research organizations in order to deliver the Lecture. He has been granted temporary leave of absence from Carnegie Institute of Technology to accept the Zurich, Switzerland, post. Dr. Mehl will deliver the lecture at 11:00 am, Feb. 16th, in the Ballroom of the Sheraton-Atlantic Hotel in New York City.

Hardly will Dr. Mehl have concluded his speech when it will be 12:15 pm and time to move to the Winter Garden room for the Iron and Steel Division's Annual Luncheon. This year's speaker will be Hjalmar W. Johnson, vice president of planning and research, Inland Steel Co. His topic will be *Midwestern Steelmaking*. Mr. Johnson has twice served terms as a director of the AIME, and during his second tenure (1953-1955) he was chairman of the Johnson Committee whose recommendations became the foundation for the organizational structure of the Institute. Among his awards is included the AIME's J. E. Johnson, Jr., Award (1933); and, more recently, The Benjamin F. Fairless Award (1959).

The All-Institute session meeting in the Grand Ballroom at 2:30 pm will hear a talk on *The Future of the Petroleum Industry in the US for the Decade 1960-1970*. Featured speaker will be John G. Winger, vice president, Chase Manhattan Bank. Immediately following will come the State of the Institute Address, by President Howard Pyle.

Later on this same Tuesday The Metallurgical Society will host its Annual Dinner in the Ballroom of the Sheraton-Atlantic. Featured speaker at this 7:00 pm dinner will be Prof. C. Stark Draper, head of the Department of Aeronautics and Astronautics, Massachusetts Institute of Technology. His subject will be *Guidance for Spacecraft*. Dr. Draper has specialized in vibration measurement, analysis, and control. He developed apparatus for recording vibration in aircraft and electromagnetic indicators for study of pressures and detonation in internal combustion engines. The military, especially, has acknowledged his contributions. In 1951 he was given an Exceptional Civilian Service Award from the Department of Air Force. The Navy bestowed its Distinguished Public Service Award on him in 1956. He was the 43rd Wilbur Wright Memorial Lecturer in 1955, as designated by The Royal Aeronautical Society, London.

At 12:15 pm Wednesday, the 17th of February, Arthur H. Dean, the well-known lawyer, will speak at the EMD Annual Stag Luncheon and Business Meeting. His topic will be *The Impact of the Anti-trust Laws on American Business and on Our Ability to Compete with the Soviet Union*. Mr. Dean has been involved in numerous anti-trust suits since joining the New York firm of Sullivan & Cromwell in 1923, and knows his subject well. He is acquainted with the metals industry, too, as the fact that he is a director of American Metal Climax, Inc., attests. The meeting will be held in the Winter Garden at the Sheraton-Atlantic.

Charles R. Kuzell will deliver the Second Extractive Metallurgy Division Lecture at 11:00 am Thursday, the 18th. Mr. Kuzell, a director of the Phelps Dodge Corp., will speak on *Modern Copper Smelting*. He began his career in 1910 on joining the Anaconda Copper Mining Co., Great Falls, Mont. Since then his career has been marked by a series of industry appointments and their resultant achievements. In 1956 he was awarded the AIME's James Douglas Gold Medal for his "outstanding contributions to nonferrous metallurgy, particularly in the field of copper smelting. . ." Mr. Kuzell is also a former AIME Director.

The Institute of Metals Division has announced that its Annual Lecture will not be given at the Annual Meeting this year. The scheduled speaker, Prof. N. F. Mott, F. R. S., Cavendish Professor of Physics, Cambridge University, is unable to attend. However, Professor Mott is expected to be able to lecture at this year's Fall Meeting in Philadelphia.

B.S. Grads, Salaries Were Up in 1959, EJC Report Shows

There were 38,162 B.S. graduates in engineering in 1959, according to latest figures released by the Engineers Joint Council. This is slightly more than the 37,965 predicted by the Council's Engineers Manpower Commission in an earlier announcement.

The class of 1959 was the largest since 1951, so found the Manpower Commission's ninth annual report, *Demand for Engineers—1959*. It also reported starting salaries at an all-time high, averaging $510 a month for B.S. graduates, $600 for M.S., and $825 for Ph.D. Aircraft, electrical equipment, and electronics industries offered the highest salaries.

Engineering turnover in 1958 averaged 9.5 pct, an 11 pct decline over 1957; when 1959 results are tabulated, they are expected to reveal an even lower 8.6 pct rate.

ASM HEADQUARTERS

Official opening of the American Society for Metals' new headquarters in Novelty, Ohio, was held on Dec. 3rd. The literal crowning glory of the building is a 250-ft diam geodesic dome, composed of 13 miles of extruded aluminum alloy tubing and tension rods reaching 103-ft overhead. The purpose of the dome is symbolic rather than structural, since it does not in any way support the building. Rather, it dramatizes man's mastery over metals.

The dome is centered on a 600-ft garden circle, which in turn is centered on a 400-ft piazza containing a mineral garden 100-ft in diam and 7-ft deep. The *garden* contains crude ores and minerals to symbolize earth's metal resources. On completion, the garden will contain 350 specimens of native minerals. Combined with the dome and garden is the semi-circular headquarters building itself. It measures 240-ft around the outer face of the 168° semi-circle, and 140-ft on the inner face. In width, the building is 53-ft, with the combined dimensions producing 50,000 sq ft of floor space.

Los Angeles Hosts April Meetings

Oxygen steel men are in for a bonus in April with the scheduling of three pertinent meetings related in time, space, and geography.

Scheduled are the Acid Converter and Basic Oxygen Steel Committee's Annual Meeting . . . Western section, NOHC, meeting . . . and the Southwest Metals and Minerals Conference. All three will be compressed into four full days, Apr. 20-23. And all will be housed in the Ambassador Hotel, Los Angeles.

Coincidentally, this same Ambassador Hotel will be host to a Manned Space Stations Symposium Apr. 20-23. Sponsors of the meeting are the Institute of the Aeronautical Sciences, Inc., National Aeronautics and Space Administration, and the Rand Corp. Among the participants will be C. S. Draper of MIT, one of the principal speakers at the AIME Annual Meeting.

Wednesday, Apr. 20th, will see the acid converter and basic oxygen steel men tour the Fontana, Calif., oxygen steelmaking (LD) facilities of Kaiser Steel Corp.

That same evening the Western section, NOHC, will have a dinner meeting during which J. E. Tredennick, division metallurgist, Iron and Steel div., Kaiser Steel, will speak on *Basic Oxygen Steelmaking*. The paper will present a review of Kaiser's experience, and a discussion of equipment and procedures in use at their plant.

The Acid Converter and Basic Oxygen Steel Committee will continue with an Off-the-Record meeting on Apr. 21st, when operating problems will be discussed. The day will also mark the beginning of the Southwest Metals and Minerals Conference.

Special Requirements for the Space Age is the theme of the joint morning session on that Thursday. Titles scheduled for presentation include: *Energy Sources and Fuels*, *Materials for the Space Age*, and *New Shielding Applications*. At noon, 1960 AIME President, Joseph L. Gillson will give the welcoming address to Conference participants. That same afternoon there will be a Boron Symposium, with papers covering the geology, mining, refining, and products of the metal.

Simultaneously, a Rock Products Symposium will be offered with emphasis on the Los Angeles area's problems. In the evening a banquet will enable registrants to get together socially. Speaker of the evening is to be Albert C. Hibbs, chief of the Division of Space Sciences at Jet Propulsion Laboratories, California Institute of Technology.

The Acid Converter and Basic Oxygen Steel Committee's Annual Meeting will continue on Friday, the 22nd, with a technical meeting on basic oxygen steelmaking. Among the scheduled papers and discussions is an examination of *The Physical Chemistry of Oxygen Steelmaking*, by D. L. McBride, director of metallurgical process development, U. S. Steel Corp.

The Southwest Metals and Minerals Conference will feature a session on beryllium metallurgy Friday morning. The concurrent mining session on Natural Raw Materials will have papers on titanium resources in New Mexico and Colorado, plus reports on rare earth metals, beryllium, and the development of space age metals.

That afternoon the metallurgists will deal with space vehicle structures. The mining session will explore Industrial Minerals, with papers on roofing granules, stone, talc, soda ash, and cement.

For those who want to stay over another day, a choice of long or short field trips to local facilities is offered on Saturday, Apr. 23rd.

Ceramics Conference at N. C. State College

A Conference on the Mechanical Properties of Engineering Ceramics will be held on the North Carolina State College campus Mar. 9-11.

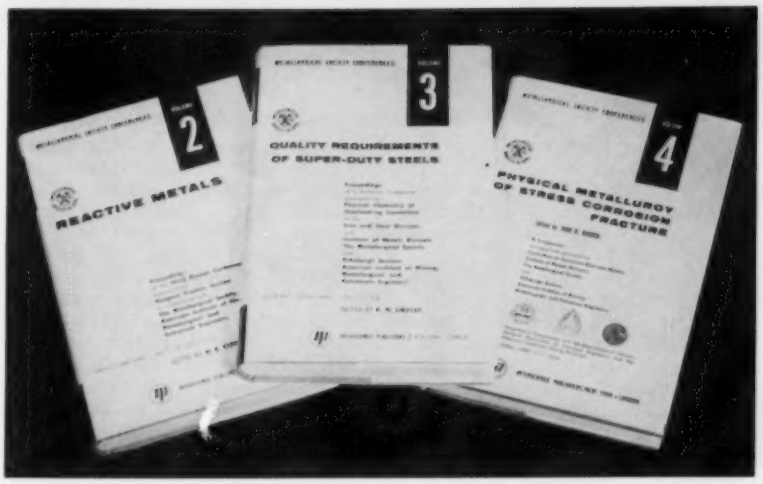
The Conference should prove of interest to research scientists and materials engineers working with ceramics, cermets, and graphite. It will be concerned with new developments relating to the fundamental parameters governing the mechanical properties of ceramics.

Keynote speaker for the Conference will be Prof. Earl R. Parker, director of the Institute of Engineering Research, University of California at Berkeley. Among the members of the advisory committee for the Conference are Pol Duwez, prof. of mechanical engineering, California Institute of Technology; and Peter R. Kosting, director of the Metallurgical Division, Office of Ordnance Research, Durham, N. C.

Arrangements and registration for the conference are being handled through North Carolina State College's Extension Division. Requests for application forms should be addressed to Dave Stansel, Box 5125, State College Station, Raleigh, N. C.

3 More Society Conference Volumes Out

Three more in the series of Metallurgical Society Conference volumes have been released. They are **Reactive Metals,** based on the Niagara Frontier section-sponsored Third Reactive Metals Conference held in Buffalo in 1958 . . . **Quality Requirements of Super-Duty Steels,** proceedings of the Pittsburgh meeting in 1958 sponsored by the Physical Chemistry of Steelmaking Committee of the Iron and Steel Division, the Institute of Metals Division, and the Pittsburgh section of AIME . . . and **Physical Metallurgy of Stress Corrosion Fracture,** product of a 2-day April 1959 Pittsburgh conference sponsored by the Corrosion Resistant Metals Committee of the IMD, The Metallurgical Society, and the Pittsburgh section of AIME.



Reactive Metals—edited by W. R. Clough—contains progress reports on 11 reactive metals, plus descriptions of the special processing techniques they are making necessary. Represented are titanium, zirconium, hafnium, thorium, vanadium, columbium, tantalum, molybdenum, tungsten, uranium, and rhenium,

The papers dealing with titanium involve heat treatment of the metal, discussion of its new alloys and strengthening techniques; use in aircraft engines; and the acid pickling of alloys. Hafnium papers present the mechanical properties of arc-cast sponge Hf, and the metal's use in fabrication of control rods. The only paper dealing with thorium covers the effect of hydrogen on tensile and impact properties.

Vanadium papers impart information on ductile-brittle transition, binary phase diagrams, and the development of alloys for reactor use. Columbium is represented by explorations of carbon/oxygen equilibrium, recrystallization, the chlorination of ores, oxidation of alloys, and solubility and structure of carbide phases.

Discussions of tantalum center on oxidation of its alloys, solubility and structure of carbide phases, and the use of Ta in electrolytic capacitors. Molybdenum papers deal with the recrystallization behavior of coated and uncoated Mo alloys. Slip casting, high-temperature internal friction studies, and the annealing of point defects come under scrutiny in the tungsten papers. Casting of uranium and the effect of heat treating salts on the metal's hydrogen content make up uranium's contribution. The sole contribution on rhenium discusses the fabrication and properties of the metal.

Price of this 624 pp. volume on reactive metals is $15; however, AIME members may have it for the 20 pct discount price of $12.

Quality Requirements of Super-Duty Steels is edited by R. W. Lindsay. It contains 16 papers, followed by discussions of the following areas.

Environment of uses and required properties . . . relationship between composition, structure, and properties . . . air melting practices . . . and special steelmaking practices. Price of the 320 pp. book to AIME members is $6.80; $8.50 to non-members.

Physical Metallurgy of Stress Corrosion Fracture is the third of the most recently issued conference volumes. The meeting last April was the first of its kind since the 1954 investigation of the subject by the Electrochemical Society. Consequently, the book represents the latest word on the subject of stress corrosion fracture.

The first half of the symposium was devoted to general principles of the three basic factors involved: stress, fracture, and chemical reactivity. This was followed by a clarification of the mechanisms of stress corrosion cracking in terms of specific environments and materials. Special emphasis was given the relationship between stress and chemical reactivity . . . concept of embrittlement by localized corrosion . . . interactions between the initiation and propagation stages of cracking and the influence of crystallography . . . effect of specific alloy compositions and chemical environments on failure mechanism . . . and application of dislocation movement to crack growth. A total of 16 papers, plus discussions are included in the 408 pp. book. T. N. Rhodin is its editor. Price to AIME members is $10.40; non-members may order it for $13.

Those who attended the conferences on which these proceedings are based will receive their copies free as part of their registration fee. Members may order these, as well as the first-issued, **Flat Rolled Products** volume, from the Metallurgical Society, 29 W. 39th St., New York 18, N. Y. Non-members must order directly from Interscience Publishers, Inc., 250 Fifth Ave., New York 1, N. Y.

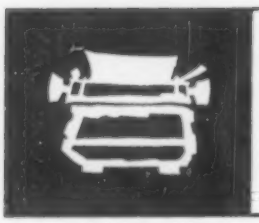
Nondestructive Testing Conference in Japan During March

The Third International Conference on Nondestructive Testing will be held in Japan during March. The Conference will be divided between Sankei Kaikan, Tokyo (March 15-18), and Mainichi Kaikan, Osaka (March 21st).

The main part of the Conference will consist of four principal sessions (two in Tokyo and two in Osaka) and several technical sessions. Titles of the principal sessions are:

1) Relation between results of nondestructive testing of materials and their mechanical strength; 2) Calibration and standard test methods of various types of apparatus and materials for nondestructive testing; 3) Nondestructive testing of materials in relation to their quality; and 4) Nondestructive testing in shipbuilding as applied to structure and power equipment.

For more information, contact: *The Secretary, Organizing Committee, Third International Conference on Nondestructive Testing, Science Council of Japan, Ueno Park, Taito-ku, Tokyo, Japan.*



STUDENT NEWS

Fortune in the guise of a suspended steel strike smiled on the Student Relations Committee of the Chicago section, AIME, to permit a successful Students' Night Program on December 10, 1959.

Invitations to participate in the annual program were issued to professors and AIME Student Chapter members at five schools in the area with which the Section maintains regular contact. The schools are: Purdue University, University of Illinois, University of Wisconsin, Northwestern University, and Illinois Institute of Technology. A conflict with final examinations limited Northwestern's representation to faculty members, but excellent turnouts were the rule in the balance of the schools, as a total of 79 students and 13 professors joined in the festivities.

A prelude to the evening program held at the Chicago Bar Association was a series of visits to area steel plants during the afternoon. Student members of the Mineral Industry Society from the Urbana campus of the University of Illinois, accompanied by Profs. C. J. Altstetter, R. W. Bohl, and R. G. Wuerker, were guests of U. S. Steel Corp. at its South works during the afternoon.

Purdue professors R. Schuhmann, Jr., R. E. Grace, Peter Winchell, and G. L. Liedl joined student members of the Purdue AIME Student Chapter in touring the South Chicago plant of Republic Steel Co.

Down from Madison came members of Wisconsin's Mining and Metallurgical Club, accompanied on a visit to Gary works of U. S. Steel Corp. by Prof. P. C. Rosenthal.

The Wisconsin Steel works of International Harvester Co. played host to AIME student members from Illinois Tech's chapter. They were accompanied by Profs. Paul Gordon and N. H. Polakowski.

Rigors of the plant trip just concluded were forgotten as student members, professors, and Chicago section members convened for the dinner meeting at 6:30, which began, fittingly enough, with a social hour featuring a certain malt beverage which is well known to all metallurgy students, past and present.

Following dinner came the formal meeting of the Section, ably chaired by the Section's Secretary-Treasurer, T. S. Bartlett, in the absence of the chairman. Mr. Bartlett extended a welcome to the students and professors attending the meeting as guests of the section before introducing the Vice Chairman of the Student Relations Committee, H. B. Dyer. Mr. Dyer credited W. P. Hoffman, Chairman of the Committee, with sparking the preparations for this meeting, even though Mr. Hoffman was unable to attend. He next introduced both students and professors from the various schools participating in the program. Faculty representatives from Northwestern were Profs. M. E. Fine and J. B. Cohen. Next to speak was D. C. Johnston, Assistant Secretary of The Metallurgical Society of AIME, who brought greetings to all at the meeting from the officers and headquarters of AIME, stressing the importance of student members to the future growth of the Institute and the interest in student activities currently undergoing a revival within the new Society organizations.

The technical portion of the evening's activities was devoted to a talk by Dr. R. M. Brick, research director, Continental Can Co. Dr. Brick discussed *Present and Future Metallurgy in the Can Industry*. In a relatively short time, he related the past, present, and supposed future of the metal-container industry from the standpoint of the metallurgist who is faced with corrosion, forming, and joining problems which can be further complicated by unpredictable variations in the chemistry of materials for which he must design practically infallible containers. Numerous questions attested to the interest among both students and practicing members of the profession in the peculiar problems of this industry.

Case Institute of Technology

Officers of the Case Metallurgical Society for the Spring semester, 1960, were elected Dec. 10th.

Lawrence Draper will be president; Peter Raffo, vice president; Daniel Harsch, secretary; Michael Rabbitt, treasurer. Dr. Willy Form of the Case metallurgical faculty is the group's faculty advisor.

Cornell University

The Dec. 10th meeting of the Cornell Metallurgical Society featured an explanation of *The Role of the Materials Research Engineer in Industry*, by Dr. Thor N. Rhodin of the Cornell metallurgical engineering faculty. Chairman Jack Finnegan presided at the Olin Hall meeting. After the talk, refreshments were served to the 16 persons in attendance.

Washington State University

The student metallurgical group at Washington State University has elected the following officers, term expiring in June: William L. Johnson, president; Delmar W. McKinley, vice president; Guy Granger, secretary; and John Williams, treasurer. Delmar McKinley also takes care of programming, while Guy Granger is in charge of membership.

Lafayette College

The John Markle Society at Lafayette College, Easton, Pa., watched a movie on *Steel in Concrete* at its Dec. 10th meeting. The film was furnished by the Bethlehem Steel Co.

Recruiting leaflet

Recruiting Practices and Procedures-1959 is the title of a recently published 8 pp. leaflet that should prove of interest to June graduates and others. The leaflet details the responsibilities of the employer, college, and student alike in placement procedures. The American Society for Engineering Education published the guide.

Prof. W. Leighton Collins, Secretary of the Society, says that "it is the hope of ASEE that this leaflet gets into the hands of every engineering senior seeking employment, as well as recruiter and college placement officers."

W. W. Burton, employment manager of the Minnesota Mining & Manufacturing Co., has said:

"This is a combination of the best thinking of representatives from both industry and education and represents the highest standards of ethical procedures yet developed."

Copies of the leaflet are being sent to Student Chapters in metallurgy schools in quantities sufficient for distribution to AIME student members only. Nonmembers may obtain it from the ASEE by contacting Prof. Collins at the University of Illinois, Urbana, Ill. Price is 10 cents per copy. Unaffiliated AIME student members may obtain their copies free by addressing Douglas C. Johnston at the AIME headquarters.

NEW STUDENT MEMBERS

University of Arizona
Stokes, James L.

Polytechnic Inst. of Brooklyn
Conti, Jack
Lane, Paul, Jr.
Leickhardt, Daniel S.

University of California
Barmore, Willis L.

Case Institute of Technology
Filkins, William C.

Colorado School of Mines
Edwards, Glen R.

Cornell University
Miller, Gerald R.

Drexel Inst. of Technology
Coleman, John R.
Gray, Edwin H.

Harvard University
Hauser, Joac Him J.
Larson, Donald C.
Suits, James C.

University of Illinois
Rogeness, Dean A.
Vytanovych, George J.

Illinois Inst. of Technology
Borra, Pier C.
Bruscato, Robert M.

Imperial College, London
Armitage, Brian
Banks, Clifford, C.

Lehigh University
Chrisman, John K.

Massachusetts Inst. of Tech.
Crimmins, David S.
Ghosh, Ahindra
Irons, George S.
Misra, Som. N.
Pease, Leander F., III

University of Michigan
Bitzer, John D.
Evans, Donald B.
Morris, Frank H.
Schultz, Jay W.
Stanley, Roy R.

University of Minnesota
Anderson, Alan A.
Chu, Ha. S.
Eriksson, James L.
Krinke, Terry A.
Math, Ferdinand S.
Roach, Maurice P.

Missouri School of Mines
Fitzgerald, Richard A.
Jain, Satya P.
Leger, Geary L.

Montana School of Mines
Chor, John J.

New Mexico Inst. of Mines
Casteel, Gary B.
Pulaski, James J.
Weber, James A.

New York University
Geller, Robert D.
Reiner, Martin J.
Reinstein, Alan H.

Purdue University
Arcella, Frank G.
Berg, Raymond B.
Jackson, Jared K.
Miller, Sterling G.
Pavlick, John E.
Percheski, John K.

Rensselaer Polytechnic Institute
Baum, Louis W., Jr.

Royal School of Mines, London
Barham, David
Haddrill, Derek M.

Stanford University
Brimhall, John L.
Kuhlken, Lawrence E.
Rojas, Gustavo

University of Toronto
Williams, Richard M.

Virginia Polytechnic Inst.
Ferry, Brownell N.
Lawrence, Robert V.

Wayne State University
Eckel, Richard P.
Gromek, George S.
Kiwak, Robert S.

University of Wisconsin
Armitage, Charles H.

Yale University
Baumgartner, Robert H.

AROUND THE SECTIONS

Lehigh Valley section played host to 105 members, ladies, and guests at its annual Ladies' Night Dec. 4th. Speaker of the evening was 1959 AIME President Howard Pyle, who spoke about *Our Primary Energy Supply*. While this technical talk was going on, the ladies adjourned to another room for a Christmas decoration demonstration by Mrs. Charles Behr.

During the business portion of the meeting, the Section's 1960 officers were nominated and elected. Robert W. Sleeman has been elected chairman; Henry J. Burnell, vice chairman (1 year); Stanley A. Ward, vice chairman (2 years); Carl B. Post, vice chairman (3 years); Robert M. Johnson, manager (1 year); Mark S. Childs, manager (2 years); and Nathan Brown, manager (3 years).

Lima, Peru's Nov. 18th section meeting featured a talk on *Lead and Zinc—The Efforts of the Working Committee of the United Nations*, by Sr. Fernando Berckemeyer, the Peruvian Ambassador to the US.

Western section, NOHC, heard a description of *Ferroalloys—Steelmaking in the Future* when it convened at the Roger Young Auditorium in Los Angeles Dec. 8th. F. E. Van Voris, metallurgical engineer with the Union Carbide Metals Co., Cleveland, made the presentation.

Washington, D. C. section was visited by 1959 AIME President, Howard Pyle, and AIME Secretary, Ernest Kirkendall, on Dec. 1st. Mr. Pyle discussed the status of primary energy resources in the US, while Mr. Kirkendall reemphasized the goal of the United Engineering Building Fund.

The meeting was also marked by the election of Section officers for 1960. Richard W. Smith has been elected chairman; John Croston, Charles W. Merrill, and J. T. Sherman, vice chairmen; Paul T. Allsman and Cloyd M. Smith, council; Albert E. Schreck, secretary-treasurer; and Donald J. Frendzel, assistant secretary-treasurer.

St. Louis section officers for 1960 are Gordon M. Bell, chairman; V. W. Buys, vice chairman; and Norman S. Geist, secretary-treasurer. The elections were made at the Section's Nov. 13th meeting.

Buffalo section, NOHC, is planning its annual Golf Party for Thursday, May 26th, at the Wanakah Country Club, Wanakah, N. Y. Section Secretary Harry A. Morlock also announces that they will depart from tradition in setting the date for their Annual Meeting this year. The meeting will be held Nov. 15th, the third Tuesday of the month, rather than the second Tuesday, election day, Nov. 8th.

Oregon section's Dec. 10th meeting played host to AIME President-Elect Joseph L. Gillson. Dr. Gillson entertained the group with a talk on production of titanium minerals throughout the world. The meeting also featured the election of 1960 officers. Those elected were Francis X. Cappa, chairman; Charles McVickers, vice chairman; and S. L. Sampson, secretary-treasurer.

Montana section was also on the itinerary of the globe-trotting President-Elect, Gillson. Dr. Gillson, who is chief geologist for the du Pont Co., presented a slide-illustrated talk on the Archeology in Mexico. His slides revealed the concepts of engineering and architecture as practiced by the ancient Aztec, Toltec, and Mayan civilizations.

The AIME President-Elect also took time to congratulate the 150 members and wives in attendance on surpassing its quota toward the United Engineering Building Fund.

Following his talk came the business portion of the dinner meeting. The chief order of business was the election of 1960 officers. Chosen were George Hanson, chairman; Guy Weaver, vice chairman; and Koehler Stout, re-elected secretary-treasurer.

Blast Furnace Group Names Nominees

The Blast Furnace, Coke Oven, and Raw Materials Committee has nominated the following individuals for terms beginning in April:

James Chisholm, Chairman
W. F. Huntley, Second Vice Chairman (two years)
D. C. Brown, Secretary
W. O. Bishop, Director (four years)
E. R. Dean, Director (four years)

These selections were made by a Nominating Committee headed by J. W. Duncan, Past Chairman. Continuing in office will be F. C. Anderko, First Vice-Chairman; R. W. Shearman, Treasurer; J. S. McMahan, E. K. Miller, Jr., John Poast, and A. D. Shattuck, members of the Executive Board.

August Semiconductors Conference Announced

Metallurgy of Elemental and Compound Semiconductors is the title of the second conference sponsored by the Semiconductors Committee of the Institute of Metals Division.

Aug. 29-31 are the dates, and Boston the place. As in last year's Conference, there will be both invited and contributed papers. Whole-day sessions on new techniques of crystal growth and heavily-doped material for Esaki tunnel diodes will take up the first two days. The third day will be devoted to a field trip, the location of which is as yet unconfirmed.

Ample opportunity for informal discussion is also being provided. And a proceedings volume—including discussions—is to be published.

Semiconductor Papers

Deadline for titles and abstracts of semiconductor papers is **Mar. 1st.** Prospective authors should confine themselves to the twin themes of the Conference:

New techniques for the preparation of semiconductor crystals, including dendritic growth of semiconductor films; and heavily-doped materials for Esaki tunnel diodes.

However, other good papers which do not fit into these two categories will be considered.

Address abstracts (up to 150 words) to H. E. Bridgers, Bell Telephone Laboratories, 555 Union Blvd., Allentown, Pa.

Powder Metallurgists Name New Officers

The Powder Metallurgy Committee of the Institute of Metals Division has named the following officers for 1960:

Harold H. Hirsch, chairman; John D. Shaw, vice chairman; Arnold R. Poster, secretary; Joseph J. Gurland, member at large (two years); and Leslie A. Seigle, member at large (to fill unexpired term of J. D. Shaw).

Set Tentative Program For May Symposium on Refractory Materials

The preliminary program for the May Refractory Materials and Alloys symposium has just been released. The 2-day symposium will be held May 25-26 at the McGregor Center, Wayne State University campus in Detroit.

The morning session on May 25th will be devoted to general metallurgy. Papers will cover the following areas: phase equilibria and relationships in refractory alloys . . . mechanical behavior of refractory metals and alloys . . . strengthening mechanisms in refractory metal systems . . . and oxidation behavior of refractory metals and alloys.

Under the heading refractory metals and alloys, the afternoon session will deal with chromium, molybdenum, columbium and their respective alloys, with particular emphasis on columbium.

The morning session on May 26th will continue the examination of refractory metals and alloys begun the day before. Under discussion will be tantalum and tungsten, plus their alloys. Rhenium and the platinum-group refractory metals will also come under surveillance.

General engineering will be the theme of the afternoon session that day. High temperature (<2000°F) strength properties of refactory metals . . . fabrication and processing of refractory metals. . . protective coatings for high-temperature environments. . . and a panel discussion on the comparative status of refractory metals for engineering applications are on tap. Still another subject will occupy the lunch hour that day when a survey of European developments in refractory metals will be presented.

The Institute of Metals Division is sponsoring the Symposium, in cooperation with the Detroit section.

For more information, contact: *C. L. Corey, Dept. of Chemical & Metallurgical Engineering, Wayne State University, Detroit 2, Mich.*

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Jan. 1, 1960, was 33,378; in addition 2,332 Student members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Brytczuk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Barnes, Alfred H., Niagara Falls, N. Y.
Barnes, Eugene H., Chicago Heights, Ill.
Binder, Ira, New Rochelle, N. Y.
Bishop, H. F., Conneaut, Ohio
Bognar, Edwin J., Pittsburgh, Pa.
Borg, Richard J., Livermore, Calif.
Brandt, Walter E., Milwaukee, Wisc.
Brucker, Paul R., Midland, Pa.
Burks, Cecil M., Weirton, W. Va.
Buzzard, Joel G., Pittsburgh, Pa.
Cahn, John W., Schenectady, N. Y.
Cargill, Howard J., Allen Park, Mich.
Clark, William D., Jr., Irvine, Pa.
Domian, Henry A., Dearborn, Mich.
Doyle, William L., Pittsburgh, Pa.
Punko, Walter P., Brookfield, Wisc.
Dyble, Edward, Erie, Pa.
Garnero, Joseph, Crete, Ill.
Grubel, Ralph O., Manilus, N. Y.
Haley, Byron J.
Hall, Warren N., Dunkirk, N. Y.
Harris, Dayton G., Independence, Ohio
Hauser, Richard E., Bethlehem, Pa.
Heydt, Gerald B., Reading, Pa.
Holmgren, David E., Berea, Ohio
Jacobs, Martin B., Pittsburgh, Pa.
Judkins, Kenneth R., Silver Bay, Minn.
Kasper, Robert J., Cleveland, Ohio
Koerber, Louis V., Baltimore, Md.
LaQue, Francis L., New York, N. Y.
Lavendel, Henry W., Chicago, Ill.
Leary, Joseph A., Los Alamos, N. Mex.
Lee, James R., Cambridge, Ohio
Leinbach, Ralph C., Jr., Bridgeport, Conn.
Lewis, William E., Pittsburgh, Pa.
Lee, Howard W., Jr., E. Chicago, Ind.
Lloyd, Evan M., Kansas City, Mo.
Louis, George A., Phoenix, Ariz.
Lull, Richard G., Malvern, Pa.
Machamer, Harry A., Jr., Earlville, Pa.
Markey, Arnold L., Los Angeles, Calif.
McGough, Frank C., E. Chicago, Ill.
Meyer, George A., Sr., St. Mary's, Pa.
Molinaro, Lawrence J., Silver Bay, Minn.
Moroso, J. C., New York, N. Y.
Myford, S. J., Warren, Ohio
Newton, Fielder N., Latrobe, Pa.
Nyburg, James L., Toledo, Ohio
Oakland, Daniel, Harvey, Ill.
Perry, Thomas E., N. Canton, Ohio
Popp, Victor T., Cleveland, Ohio
Rector, John H., Richland, Wash.
Reese, Thurston F., Atlanta, Ga.
Samways, Norman L., Pittsburgh, Pa.
Seidemann, Herman J., Jr., Kellog, Idaho
Semick, Daniel, Cleveland, Ohio
Gladu, Roger B., Sorel, Quebec, Canada
Slatosky, William J., Pittsburgh, Pa.
Stembridge, James L., Gilmer, Tex.
Sullivan, John P., Bridgeville, Pa.
Thomson, Edward A., Sault Ste. Marie, Ontario, Canada
Thomson, W. J., Arvida, Quebec, Canada
Tiemann, H. N., Hartford, Conn.
Voss, Anthony J., E. Chicago, Ill.
Wilkinson, Frederick, New York, N. Y.
Wood, Richard A., Columbus, Ohio
Young, Roy B., Ray, Ariz.
Zambrow, John L., Bayside, L. I., N. Y.
Ziemkiewicz, Leonard P., New Kensington, Pa.

Associate Members

Hilburn, John P., Tampa, Fla.
Levedag, Edgar P., New York, N. Y.
Marchi, Marino L., Tarentum, Pa.
Matulis, Stanley, Lachine, Quebec, Canada
Nock, Gilbert J., Cleveland, Ohio
Schmidt-Fellner, A. N., New York, N. Y.
Smith, Frank A., Pittsburgh, Pa.

Junior Members

Adler, Philip N., Clifton, N. J.
Beernstsen, Donald J., Milwaukee, Wisc.
Bruner, Henry K., Cambridge, Ohio
Haughton, Paul E., Chattanooga, Tenn.
Howlett, Brian W., Cambridge, Mass.
Hutkin, Irving J., Indianapolis, Ind.
Meleran, Harvey B., Army Chem. Ctr., Md.
O'Hara, John R., Cleveland, Ohio

Moss, Gerald L., Aberdeen, Md.
Potts, Jerry N., Lansing, Ill.
Singleton, Ogle R., Richmond, Va.
Wortman, Oscar, Lemont, Ill.

REINSTATEMENT

Member

Hobstetter, John N., Philadelphia, Pa.

Junior

Anthony, John E., Latrobe, Pa.

REINSTATEMENT—CHANGE OF STATUS

Junior to Member

Eichen, Edwin, Brackenridge, Pa.
Haskell, Arthur C., Jr., Lewiston, N. Y.
Paynton, William C., Attleboro, Mass.

CHANGE OF STATUS

Associate to Member

Paul, R. N., Watervliet, N. Y.

Junior to Member

Cannon, Howard S., Evergreen Park, Ill.
Cathcart, Raymond G., Lake Jackson, Tex.
Cremens, Walter S., US Air Force, Europe
Eichenberg, John D., Pittsburgh, Pa.
Gleason, David S., St. Paul, Minn.
Halfacre, Robert E., Carteret, N. J.
Halley, James H., Hayden, Ariz.
Harris, Homer E., Topsfield, Mass.
Karry, Russell W., Monroeville, Pa.
Kazmierski, H. M., Chile, S.A.
Lattin, Judson M., Dolton, Ill.
Reddy, Richard L., Niagara Falls, N. Y.
Reiter, Stanley F., New Haven, Conn.
Sherman, Russell G., Hartford, Conn.
Wills, Frank, New York, N. Y.

Student to Member

Uys, Johannes M., Brackenridge, Pa.

SPECIAL REINSTATEMENT

Member

Berg, Eric A., Littleton, Colo.

OBITUARIES

Vaughan, Walter L. (member 1958) died in an airlines crash near Charlottesville, Va., on Oct. 30th. At his death, Mr. Vaughan was a sales engineer with the Kensington Steel div. of Poor & Co., Chicago.

Stoughton, Bradley (member 1897) died of a heart attack at his home in Bethlehem, Pa., on Dec. 30th. He was 86 years old. Dr. Stoughton was dean emeritus of Lehigh University's College of Engineering, having served as professor of metallurgy from 1923 to 1939 and dean of the College 1938-1939. AIME members will best remember him as Secretary of the Institute, a position which he held from 1913 to 1921.

The Legion of Honor member is known for his invention of a convertor used to make steel castings. He also developed a process for oil melting in cupolas. His career was marked by numerous contributions to both the metals industry and the National defense.

It was Dr. Stoughton's study of the technical aspects of shifting the American steel industry from a 12-hr to 8-hr working day that led to the change during the early 1920's. He was a defense adviser during both world wars: a member of the General Engineering Co. of the National Council of Defense during World War I, and chief of the heat treating equipment unit, War Production Board, in World War II.

Dr. Stoughton was both an educator and practitioner in metallurgy. He taught at Massachusetts Institute of Technology and Columbia University, in addition to Lehigh University. Industry assignments included the Illinois Steel Co., American Steel & Wire Co., and Benjamin Atha & Co. He was a director of the Lukens Steel Co. at his death.

GEORGE F. WEATON

An Appreciation

by J. G. Wehn & C. C. Long

George F. Weaton (Member 1932) died at his home December 4, 1959. Retired as Manager of Josephtown Smelter in 1954, he had served as Consultant for St. Joseph Lead Co. until the end of 1958.

Born on a farm at Cherry Valley, N. Y., on July 12, 1886, Mr. Weaton went to work as an apprentice with the General Electric Company at Schenectady at an early age. His brilliant mind, complemented by a high order of mechanical ability, brought assignment of important responsibilities in the development of the steam turbine. Success here led to a berth as power plant engineer with the J. & P. Coates Co. in 1908. Here he served until World War I, when he joined Thomas A. Edison as chief engineer.

In 1921, St. Joseph Lead Co. called him to southeast Missouri to manage the construction and operation of the River Mines power plant. Here, Mr. Weaton pioneered developments in coal-fired boilers. So successful were his innovations in steam generation that St. Joe asked him to assist in the integration and modernization of their lead mining and milling properties. During the mid-20's, Mr. Weaton made important contributions to the beneficiation of southeast Missouri ores especially with respect to grinding, classification, thickening, and flotation.

St. Joe began pilot plant research on an electrothermic method for producing zinc vapor from zinc sinter and coke at Herculaneum, Mo., in 1926. In a few months the need for a strong leader willing to take responsibility for unconventional approaches became apparent. Thus began Mr. Weaton's career as a metallurgist—a career marked by such milestones as electrothermic zinc oxide . . . electrothermic zinc metal . . . the famous Weaton-Najarian condenser . . . deleading of zinc concentrates . . . innovations in sinter manufacture . . . and recovery of zinc metal from lead blast furnace slag.

Under Mr. Weaton's energetic leadership, Josephtown Smelter was expeditiously constructed and began operations in the last days of 1930. No more severe test of either the technical and economic soundness of Mr. Weaton's metallurgical creation or the leadership of his coterie of dedicated metallurgists can be imagined than the successful commercialization of the electrothermic process in the teeth of the Nation's most profound depression.

While Mr. Weaton's personal achievements in metallurgy—especially the electrothermic furnace epic—are brilliant in their own right, perhaps his greatest contribution to metallurgical engineering was his insistence that his younger associates develop professionally. In an industry in which skeleton organizations and strict attention only to immediacies are often the rule, Mr. Weaton stood out as a prophet of the days ahead when the economic necessity of relying on technical leadership for survival would be recognized. Toward this end, he arranged for many of his associates to participate actively in the affairs of technical and professional societies. His keen interest in strengthening AIME was expressed both by copious contributions to metallurgical literature and by solid support of committee activities. Of all his many business, civic, and professional organizations, he felt closest to AIME.

His contributions to the profession both through his associates and his personal endeavors mark George F. Weaton as an engineer of distinguished achievement. With his passing, we lose a sympathetic counsel but retain a stimulating memory.

NECROLOGY

Date Elected	Name	Date of Death
1958	Adams, Marion K.	Apr. 20, 1959
1957	Bachtell, Robert G.	Sept. 28, 1959
1930	Bradley, John D.	Nov. 26, 1959
1956	Buvens, J. A.	Unknown
1899	Chippendale, Arthur (Legion of Honor)	Nov. 21, 1959
1949	Dempster, R. C.	Oct. 24, 1959
1938	Elstad, R. T.	Dec. 14, 1959
1914	Fettke, Chas. R.	May 26, 1959
1939	Godard, J. S.	July 22, 1959
1952	Grant, Edward S.	Oct. 19, 1959
1922	Haddock, J. C., Jr.	Nov. 10, 1959
1905	Hamilton, S. H. (Legion of Honor)	Dec. 18, 1959
1921	Hobson, George V.	Mar. 16, 1959
1909	Jackman, H. E. (Legion of Honor)	Oct. 29, 1959
1956	James, R. E.	Aug. 29, 1959
1956	Johnston, D. C., Jr.	Mar. 22, 1959
1956	Kershaw, Chet A.	July 18, 1959
1957	Lowrey, H. E.	Unknown
1937	Mace, Clement H.	Apr. 5, 1959
1946	McGivney, Thomas F.	Unknown
1937	Morgan, William M.	Oct. 7, 1959
1950	Morton, Byron B.	Aug. 14, 1959
1954	Mulcahy, B. P.	Aug. 31, 1959
1955	Neal, James C.	Aug. 15, 1959
1946	O'Leary, George	1958
1914	Radcliffe, Don H.	Apr. 27, 1959
1929	Rosaire, E. E.	Sept. 21, 1959
1936	Schultz, Robert R.	Dec. 6, 1959
1958	Seelinger, Adolph L.	August 1959
1918	Smith, Erwin W.	Oct. 23, 1959
1956	Spalding, J. C., Jr.	Sept. 29, 1959
1950	Staats, Fred	Sept. 25, 1959
1956	Stevens, P. S.	Oct. 26, 1959
1897	Stoughton, Bradley (Legion of Honor)	Dec. 30, 1959
1959	Thornburg, Garth W.	Oct. 18, 1959
1958	Vaughan, Walter L.	Oct. 30, 1959
1932	Weaton, George F.	Dec. 4, 1959
1923	Weichel, Edgar C.	Sept. 10, 1959
1938	Wright, Fay L.	Oct. 2, 1959
1939	Zerbe, William F.	Unknown

Coming Events

Feb. 12, Southwestern section, NOHC, Spring Meeting, Lennox Hotel, St. Louis.

Feb. 14-18, AIME Annual Meeting, Sheraton-Atlantic Hotel (formerly McAlpin) and Hotel Statler, New York.

Feb. 16-19, Symposium on Hydrometallurgy, *Wet Processing of Minerals and Industrial Products*, The Australasian Institute of Mining & Metallurgy, Adelaide, Australia.

Mar. 9-10, Symposium on Processing of Materials for Re-entry Structures, The Mid-West Society of Aircraft Materials and Process Engineers, Dayton, Ohio.

Mar. 14-18, 16th Conference on Corrosion, National Association of Corrosion Engineers, Memorial Auditorium, Dallas, Tex.

Mar. 15-21, Third International Conference on Nondestructive Testing, Tokyo, Mar. 15-18; Osaka, Mar. 21.

Mar. 29-31, 22nd American Power Conference, co-sponsored by AIME, Hotel Sherman, Chicago.

Apr. 3-8, Sixth Nuclear Engineering and Science Conference, Coliseum, New York.

Apr. 4-6, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

Apr. 19-22, International Symposium on the Metallurgy of Plutonium, sponsored by the Societe Francaise de Metallurgie and the French Atomic Energy Commission, Grenoble, France.

Apr. 21-22, Southwest Metals and Minerals Conference, Ambassador Hotel, Los Angeles, Calif.

Apr. 25-27, Powder Metallurgy Show, sponsored by Metal Powder Industries Federation, Drake Hotel, Chicago.

Apr. 28-30, AIME Northwest Regional Conference, Sheraton Hotel, Portland, Ore.

May 4, Chicago section, NOHC, Spring Dinner Meeting, Phil Smidt's Restaurant, Hammond, Ind.

May 9-13, American Foundrymen's Society, National Castings Congress and Exposition, Convention Hall, Philadelphia.

May 24-26, American Society for Quality Control, Annual Convention, San Francisco.

May 25-26, AIME Symposium on Refractory Metals and Alloys, McGregor Memorial Conference Center, Wayne State University, Detroit.

May 26-27, The Metallurgical Society, New England Regional Conference on *New Developments in Metalworking*, Statler-Hilton Hotel, Boston.

June 9-10, AIME Columbium Symposium, sponsored by the Hudson-Mohawk section, Hotel Sagamore, Lake George, N. Y.

June 13-15, First International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPIF.

July 11-12, AIME Conference on the Response of Materials to High-Velocity Deformation, Estes Park, Colo.

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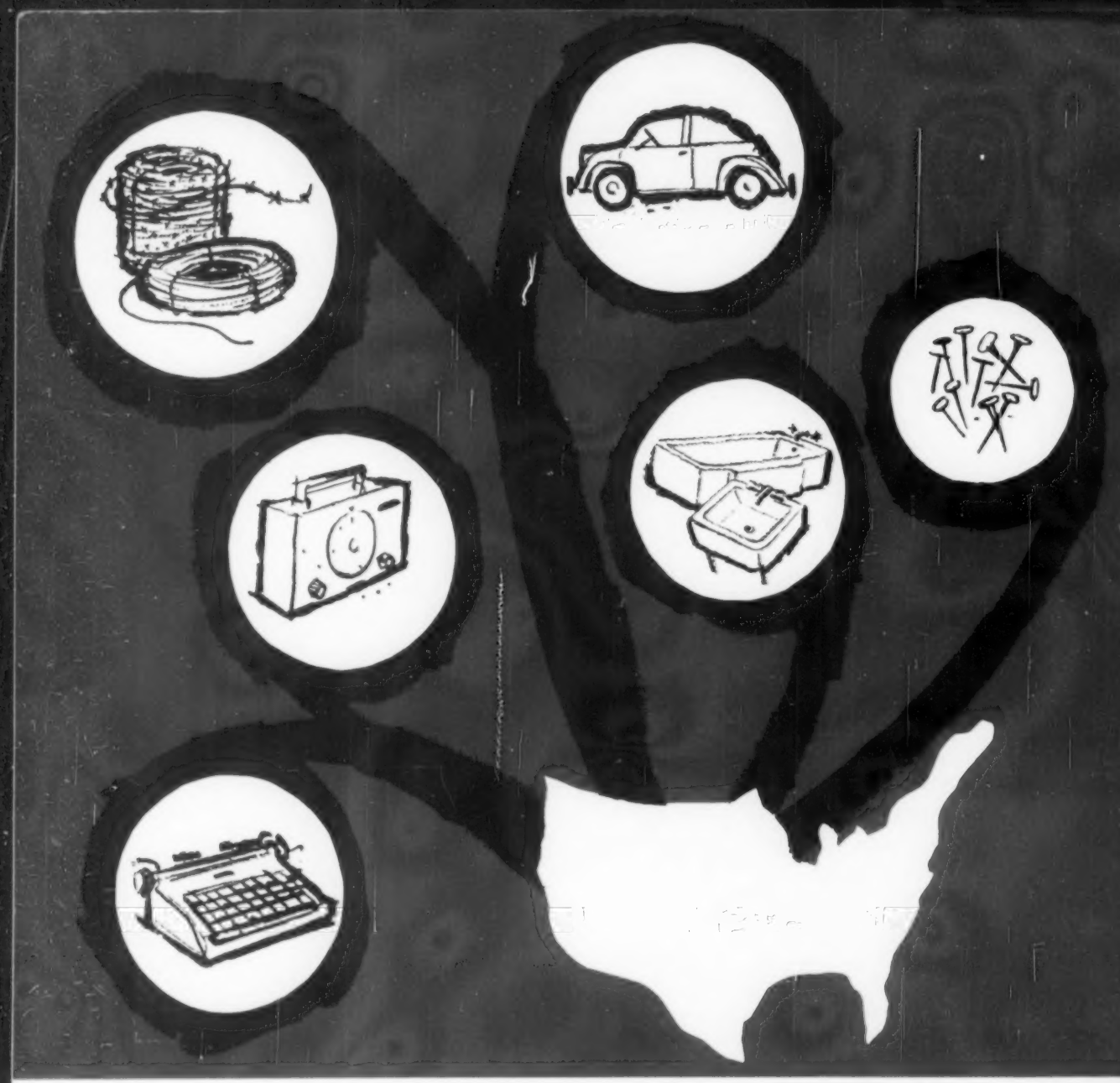

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